Confronting Land Degradation and Climate Risks in Dryland Agro-ecosystems

Examining dryland degradation through the lens of vulnerability in Jodhpur, India

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Declaration of Ownership

I, Darshini Ravindranath confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Darshini Ravindranath

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Abstract

Drylands cover nearly half of the earth's terrestrial surface and are home to unique ecosystems and vibrant cultures. Dryland communities face various challenges of living in the harsh and variable conditions presented by their environment and landscapes. These challenges are magnified in the arid landscapes of India, where agriculture is largely rain-fed and human and livestock population densities are some of the largest in the world. Communities and landscapes in arid India are exceptionally vulnerable due to intensifying dryland degradation, increasing rainfall variability along with climate change.

This thesis contributes to a critical research area by developing and applying a methodological framework centred on 'vulnerability' for investigating dryland degradation in India's arid landscapes. Dryland degradation is studied as a synthesis of the complex interactions between socio-ecological system functions within inherently dynamic environments. The empirical basis for the study is the use of mixed methods incorporating primary and secondary data, enriched by community perspectives. The study provides new insights through findings on the interactions between land use, land degradation, and climate risks. It addresses gaps in drylands research, especially in the development of a context specific vulnerability framework for drylands. It, furthermore, uses this framework to provide recommendations to confront dryland degradation while planning for effective adaptation.

Overall, the analysis finds that the dominant narrative in India - of poor farmers in the Thar desert struggling to cope with drought, in need of protection from their natural environment – to be fundamentally misplaced. However, as their land becomes increasingly degraded and their surrounding climate less predictable, their socio-cultural systems and institutions become less resilient. As a result, arid zone farmers are now more likely to turn to strategies that aim for short-term solutions, which may only exacerbate vulnerability and land degradation in the longer term.

Key words: Agriculture; Drylands; Dryland degradation; Rajasthan; India; Adaptation; Climate change; Vulnerability; Rural livelihoods

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Acronyms

AgLiVI	Agriculture and Livelihood Vulnerability Index
AR	Assessment Reports (of the IPCC)
CAZRI	Central Arid Zone Research Institute
CGWB	Central Ground Water Board
CPR	Common Property Resources
CRIDA	Central Research Institute for Dryland Agriculture
DAP	Diammonium Phosphate
DDP	Dryland Development Paradigm
FAO	Food and Agriculture Organisation
GEF	Global Environment Facility
GLADIS	Global Land Degradation Information System
GoI	Government of India
GoR	Government of Rajasthan
Ha	Hectare
HDI	Human Development Index
HH	Household
HoH	Head of Household
HYV	High Yielding Variety (seeds)
ICAR	Indian Council for Agriculture Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IGNP	Indira Gandhi Nahal Project (canal)
IIED	International Institute for Environment and Development
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
ISRO	Indian Space Research Organisation
JJAS	June, July, August, and September
KCC	Kisan Credit Card (for farmers)
LDN	Land Degradation Neutrality
LPG	Liquefied Petroleum Gas
MCM	Million Cubic Meter
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Scheme
Mha	Million hectares
mm	Millimetres
MoEFCC	Ministry of Environment, Forests and Climate Change
NAFCC	National Adaptation Fund on Climate Change
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NICRA	National Innovations on Climate Resilient Agriculture
NITI	National Institution for Transforming India
NRSC	National Remote Sensing Centre
PAR	Pressure and Release
PDS	Public Distribution System
PRI	Panchayat Raj Institutions
SC/ST	Scheduled Caste and Schedules Tribes of India
SDG	Sustainable Development Goal
SHG	Self-help Group
TGA	Total Geographic Area
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
USLE	Universal Soil Loss Equation

Preface

In 2012, during the Rio+20, the UNCCD announced an ambitious initiative to commit to a vision of land degradation neutrality (LDN). The vision is also anchored strongly in the SDG 15.3 – "aim to achieve a land-degradation neutral world by 2030". During the Paris COP-2015, neutrality was set to be achieved through a LDN fund, by halting land degradation and improving land resources through financing the rehabilitation of 12 million hectares of degraded land. In June 2014, even prior to COP 2015, the Government of India, made an announcement of its own: the aim for the country to become land degradation neutral by 2030 (GoI, 2013a). While global plans to achieve LDN are progressing, albeit at a slow pace, in India, no new programmes have been launched. Meanwhile an agrarian crisis has been brewing for some time, affecting 70% of India's population that directly depend on the land for sustenance. Nearly a third of India's land is degraded, the rains destroy close to 20 million hectares of crops every year and only 20% of India's farmers are insured. Nearly 300,000 farmers, cultivators and agricultural labourers have ended their lives in the last 20 years, and reports suggest that the rate of farmer suicides has increased in the past five years due to drought and distress (Basu et al., 2016). To mitigate this growing crisis, boosting crop productivity has remained the main policy instrument of choice and plans to ensure sustainable land and water management have taken a back-seat.

I have experienced the adverse effects of land degradation, drought, and climate variability first-hand, through staying and working with India's diverse rural communities. Prior to beginning my doctoral studies, I worked with local level implementers from government, NGOs, local panchayats and international development agencies. In particular, I worked on three projects that left a mark, and influenced my choice of research. The first: evaluating socio-economic benefits of a long-term biomass energy project funded by an international development agency; the second: to mainstream climate change into a development bank's projects portfolio and the third: a research project in a semi-arid and drought prone rural community, focusing on incorporating vulnerability and adaptation planning into state-wide green growth strategies.

In completing each of these projects, I had a similar realisation; the projects had strong and impactful objectives - to improve agricultural productivity, increase forest cover, and promote equity among the rural communities that they were meant for. Unfortunately, the interventions did not always translate effectively in practice. Many of the set interventions were reactionary, with many of the programmes aimed at providing relief after the drought, flood, or a natural disaster event had occurred, rather than building the long-term resilience of rural communities to cope with such events. A common practice I came upon in areas of low water availability was a fixation with excessive digging of borewells to extract ground water for irrigation, heralded on by national government policy that promotes irrigation, accelerating groundwater decline.

Through this, I was frustrated with the lack of focus placed on diagnosing the problem and its complexity; instead seeking quick-fix solutions for complex and rooted problems. In a desire to fund 'poverty reduction' and 'meet development goals', most governmental and development agencies appeared to have limited understanding of the socio-political and ecological context within which the challenges occur. Unfortunately, the resilience of local communities, particularly in arid and semi-arid zones and the knowledge held by generations that have lived off the landscapes and experienced climate vagaries have been discounted.

Land resources have gone from being an intrinsic part of socio-cultural existence, to essentially a crutch upon which millions of Indian farmers rely. The magnitude of the problem of dryland degradation also hints at the size and complexity of the challenge. This thesis explores these issues, with the objective of diagnosing the socio-ecological vulnerabilities that surround persistent dryland degradation. It aims to inform the preparation, design, and implementation of better programmes that aim for sustainable land and water management, in the context of increasing climate variability and change, while being cognisant of mitigating the adverse impacts on vulnerable households while promoting local resilience.

1. Introduction

This thesis is an investigation into the socio-ecological factors surrounding land degradation in drylands. Specifically, it analyses the role played by 'vulnerability' in shaping dryland degradation through its influence on agriculture and livelihoods, in the arid district of Jodhpur in Rajasthan, India. The thesis uses local knowledge at multiple local scales and proposes a new approach to understanding the drivers of degradation and its interlinkages with climate risks, keeping in mind the unique and tenacious nature of India's diverse drylands. The research and its findings address critical gaps identified in drylands research today, contributing to a growing body of literature on anticipating and planning for vulnerability in dryland agro-ecosystems that face high risks of continued resource degradation and climate change.

This chapter begins by underscoring the urgency of this research, and why India and, more specifically, Jodhpur, Rajasthan was selected as a focus for exploring these debates in more detail. The research approach, overall aim and research objectives are then introduced. The chapter concludes by outlining the structure of this thesis.

1.1 Background and context: Global drylands

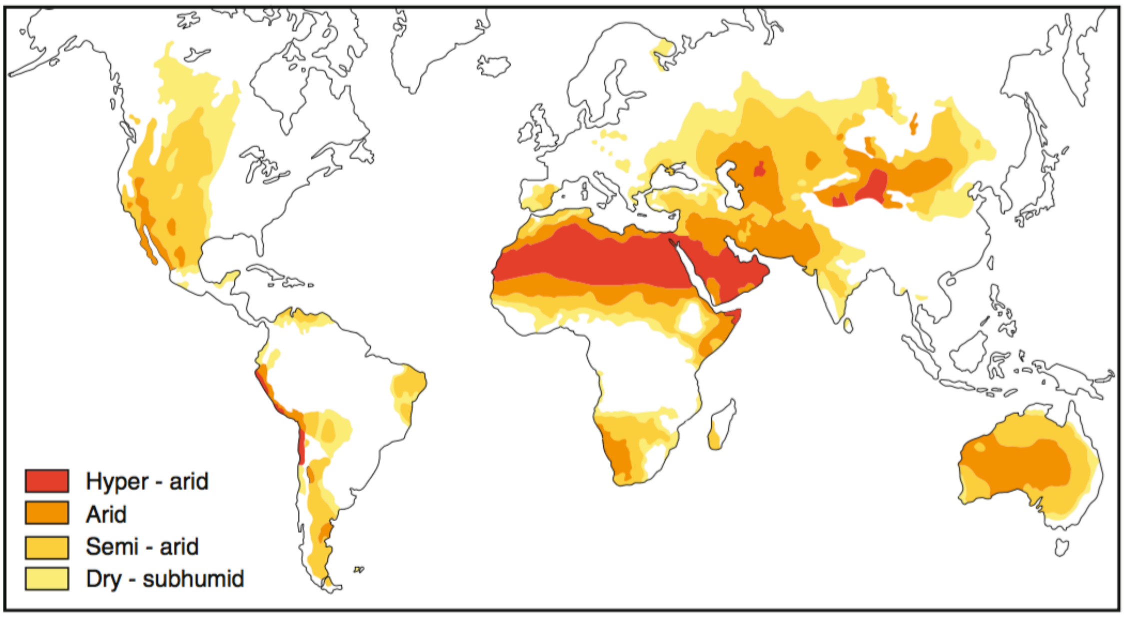
> **"It is essential to understand and address the dual challenges of land degradation and climate change if we are to meet targets, such as proposed by the sustainable development goals, tackle poverty and address many of the most pressing environmental challenges of the 21st century"**
> **(UNCCD, 2015)**

Drylands cover nearly half of the earth's terrestrial surface and are home to distinctive ecosystems and vibrant cultures that have evolved together for centuries. Drylands are limited by soil moisture, a result of low rainfall and high evapotranspiration (Safriel & Adeel, 2008). The United Nations Convention to Combat Desertification (UNCCD) define drylands as land areas with an aridity index[1] of less than 0.65(UN, 2011). In practical terms, this value indicates the maximum quantity of water capable of being lost, as water vapour, in a given climate, by a continuous stretch of vegetation covering the whole ground and adequately supplied with water (Koohafkan & Stewart, 2008). Drylands show a gradient of increasing primary productivity, ranging from hyper-arid, arid, semi-arid to dry sub-humid. Deserts, grasslands, and woodlands are the natural expression of this gradient (Shariat & Assareh, 2009). Drylands support multiple ecosystem services, play a major role in global biophysical processes, maintain the balance of several atmospheric elements, and reflect and absorb solar radiation (Koohafkan & Stewart, 2008).

[1] The aridity index is a measure of the ratio between average annual precipitation and total annual potential evapotranspiration

Drylands sustain nearly 40% of the world's population, 90% of whom live in the Global South (Safriel, 2009). Historically, these regions played a central role in development of human societies, with domestication of plants and animals, creation of the city and the growth of at least three major religions can be traced to drylands (Middleton, 2009). The current socio-economic condition of dryland populations is poor, lagging significantly behind the rest of the world, in terms of most developmental indicators (Mortimore, 2009). For instance, drylands have the highest infant mortality rates (Safriel & Adeel, 2005), and the majority of their populations live below the poverty line (Kwon et al., 2016). Agriculture is the main source of sustenance; drylands constitute nearly half of global farmland and support 50% of the world's livestock (UNDP, 2013). Despite the fragility of their ecosystems, they contain major wildlife habitats and they are home to uniquely adapted plants and animals. Figure 1.1 shows the world's distribution of drylands.

Figure 1.1: World distribution of drylands



Source: Mueller et al. (2014)

1.2 Dryland degradation: An urgent agenda for research

Limited by water scarcity and high temperatures, drylands are subject to multiple environmental stressors. These factors aggravate challenges of land degradation and desertification. Land degradation is defined as the persistent reduction of land's biological and/or economic production capacity, or as the long-term loss of land ecosystem functions and services (Mythili & Goedecke, 2016; Nachtergaele et al., 2010; von Braun et al., 2013). Desertification is defined as land degradation in arid, semi-arid and sub-humid areas of the world (UNCCD, 1993). In this thesis, the term dryland degradation is used to refer to land degradation in drylands[2]. Dryland degradation is an ongoing and relentless global problem, posing a long-term challenge to biomass productivity, food security, biodiversity and environmental sustainability (Mueller et al., 2014; Reed et al., 2011). Steinfeld et al., (2006) estimated that about 20% of global pasture and 73% of the rangelands in the world's drylands are already degraded. Dryland degradation will most impact the two billion people that live on these lands, eking out a living on traditional adaptive capacities that have served them well until recent increases in land degradation (Thomas et al., 2014).

In addition, global circulation models confirm the already detectable trend that climate change will further exacerbate the challenges faced in drylands today. Several studies have shown that drylands are likely to face increasingly unpredictable climatic conditions, extreme weather events, and are projected to become more arid (Berg et al., 2016; Feng & Fu, 2013; Huang et al., 2017; Sherwood & Fu, 2014). For the communities and landscapes that are already water-scarce, this will exacerbate drought occurrences, increase evapotranspiration and lead to lower productivity of grains.

1.3 Planning for drylands: The forgotten biome

Dryland communities across the world vary according to their socio-ecological context. However, a shared attribute is their high levels of resilience that helps them survive their dynamic ecosystems (Behnke & Mortimore, 2016). More recently, growing pressures from land degradation and a general lack of investment in drylands, are putting extraordinary strains on the livelihoods of dryland inhabitants and the integrity of their ecosystems (Thomas et al., 2014).

It is in this context that the UN Sustainable Development Goals (SDGs) stress the urgent need to tackle land degradation if overall sustainable development is to be achieved. Target 15.3 of the Sustainable Development Goals (SDGs) sets out a new global ambition: to achieve a Land Degradation Neutral World by the year 2030[3] (UN, 2017). One of the key aims is to design sustainable interventions that minimise adverse outcomes of stress (Griggs et al., 2013). Prior to the SDGs, in reviewing progress on the Millennium Development Goals (MDGs), the UNDP (2011) highlighted that the development community had for too long overlooked the two billion people living in drylands, and called for immediate action to reverse this history of neglect in following development goals (UNDP, 2011). The UNCCD, is a convention specifically designed to address the needs of dryland communities and has brought

[2] The term dryland degradation is used except when referring to research or reports that specifically use the term 'desertification'. Chapter Two provides further details on the terminologies.
[3] The UNCCD (2017) defines land degradation neutrality as a state whereby the amount of healthy and productive land resources, necessary to support ecosystem services, remains stable or increases within specified temporal and spatial scales.

international focus to the challenges of drylands. It is however one of weaker UN conventions, owing to a lack of both funding and political will (Conliffe, 2011).

Scientific enquiries conducted in drylands, especially the arid and hyperarid drylands, are also lacking in comparison to other ecosystems. Durant et al., (2014) report that between 2000 and 2011, a majority of scientific publications in ecology focussed on the forest biome (67%) while only a small proportion (9%) focussed on deserts. This lack of scientific interest transfers to a lack of financial assistance. For instance, despite the Sahara desert covering 43% of Africa's land, the desert biome only received 12% of Global Environment Facility (GEF) funding to Africa over the period 1991–2009 (Durant et al., 2014).

A recent study by Huang et al., (2017) shows that the Paris Agreement's goal of limiting average global warming to less than two degrees Celsius has not taken into consideration the impact of this limit on drylands. The authors show that warming over land is unlikely to be evenly distributed, with drylands showing enhanced warming of 20-40% in comparison with humid lands (Huang et al., 2017). Thus the 2-degree goal will be insufficient to protect the world's drylands (ibid.). The authors indicate that the risks of agricultural, hydrological, health, and drought-related concerns will increase substantially over drylands if global mean surface warming rises from 1.5 to 2.0 degree Celsius. Studies that diagnose dryland problems (Reed & Stringer, 2016), develop proposals for actions, and monitor and assess both problems and solutions are therefore essential.

1.4 India's drylands: Setting the scene

Dryland problems are particularly magnified in the arid landscapes of India, where agriculture is largely rain-fed and human and livestock populations are some of the largest in the world[4]. For these vast populations, land is an assertion of their socio-cultural heritage and, land resources the main source of sustenance. The arid zones of India are also relatively newer areas to be impacted by climate change and climate variability. This has added tremendous pressure on natural resources in the arid zones. Both communities and landscapes in arid India are exceptionally vulnerable due to exacerbation of existing stress factors such as water scarcity, land degradation, poverty, and food insecurity.

About 69% of India's total geographic area (TGA) covers drylands, of which 50.8 Mha land area (15.8% of TGA) is arid, 123.4 Mha (37.6%) is semi-arid and 54.1 Mha (16.5%) is dry sub-humid. Estimates show that land degradation has affected approximately 29% (96 Mha) of

[4] India occupies only 2.4% of the world's geographical area, yet supports about 16.7% of the world's human population; it has only 0.5% of the world's grazing land but supports 18% of the world's cattle population. Human populations in Rajasthan, one of India's dryland states is around 200 persons/sq.km and livestock populations are around 160/sq.km.

India, of which 86% (83 Mha) are in drylands[5] (Ajai et al., 2009). Observations of environmental degradation in the drylands of India, especially in arid and semi-arid tracts, are burgeoning and replacement costs mounting[6] (Reddy, 2003; ISRO, 2013).

Despite these growing pressures, India's arid drylands are one of its most marginalised and overlooked ecosystems. Political will, scientific research, and developmental programmes are severely lacking; and despite goals of achieving 'zero net land degradation by 2030'[7] (GoI, 2014), progress on this agenda is limited. Unfortunately, research in India portrays the arid regions as poor and decrepit regions, where production potential is low and the people in need of rescue. Maji et al., (2010: 8), writing for Indian Council of Agricultural Research (ICAR), call arid zones in the north-west of India, "a dreary barren desert". Mann (1993: 12) and Kar (2014b) both in studies in the arid areas of Western Rajasthan, state contemporary dryland degradation in India to be a "purely anthropological process"; dryland farmers are often presented as agents of degradation, mismanaging their resources for maximum exploitation.

A detailed diagnosis of constraints, which explain the processes and feedback effects leading to perpetuation of such behaviours, is lacking. Solutions to dryland degradation are thus largely externally driven; these are often generic solutions that rely on technical recommendations, without due consideration of the use-value of land or the specifics of local vulnerabilities. Therefore, a practical understanding of the factors that drive dryland degradation and vulnerability is essential to develop and implement measures for sustainable land management.

In India, while land policies form a crux of the country's national development plans since Independence, the focus tends to be on gaining maximum benefit from the land, rather than promoting sustainable land management. Managing drylands in a diverse country such as India, is a challenging task, given that the processes that create problematic situations evolve in various ways depending on the local context (Sietz et al., 2012). Various pressures are translated into different outcomes based on the local context. This is one of the key problems dogging successful implementations of land degradation targets even on a global scale. Meanwhile, the people living in these environments, who possess matchless knowledge of land, continue to be perceived as peripheral and unimportant at best or as agents of degradation at worst; they are neglected in most research into the development of drylands (Durant et al., 2014).

[5] Ajai et al., (2009) in writing for the NRSC, use the term desertification to define land degradation in drylands. The boundaries of arid, semi-arid and dry sub-humid regions of the country are superimposed on the digital surface models of India to find out the area under desertification.

[6] Area under desertification (arid, semi-arid and dry sub-humid regions of the country) during 2011-13 is 82.64 mha; whereas, during 2003-05 was 81.48 Mha.

[7] Govt. of India's Ministry of Ministry of Environment and Forests in 2013, stated that India must aim to become land degradation neutral by 2030.

Drylands research and its reportage in India thus lacks coverage that highlights the productive potential of drylands; it under-values the local knowledge held by dryland communities. Policymakers, therefore, hold many misconceptions about drylands, leading to few government policies or planning processes that can support current livelihoods instead of looking to shift or transform them. A critical step prior to seeking the attention of policymakers should be to focus on critical knowledge gaps persisting in drylands research, and finding innovative solutions to tackle them.

1.5 Identifying the knowledge gaps: The role of vulnerability

It is now widely acknowledged that both biophysical and socio-economic driving forces should be considered to design strategies to achieve land degradation neutrality. Despite affirmation of these principles, there are no established frameworks to understand both drivers and pressures on land, and reciprocal feedback effects (Reed et al., 2008; Reynolds & Smith, 2007; Tarrasón et al., 2016; Whitfield et al., 2011; Whitfield & Reed, 2012). The main challenge faced by researchers and policymakers has been the inability to unravel varying levels of interactions between biophysical, social and climatic phenomena that occur on multiple temporal and spatial scales (Mortimore, 2009). Many dryland researchers have supported the call for more field-driven studies at multiple scales. For example, Van Walsum et al., (2014) highlighted their belief in the need for a 'participatory research process' with local farmers to bridge the gap between local experience and scientific evidence.

Dryland degradation has natural and human-induced drivers, which interact with each other and lead to the current state. There is no definitive way to acknowledge which is more significant. What should be addressed is the need for research that addresses nature's complexity while also addressing the socio-economic complexity of human lives. To develop such conceptualisations, a logical first step is to understand the endogenous factors driving human-environment vulnerability. Here, vulnerability refers to the propensity or predisposition of the socio-ecological system to be adversely affected; it encompasses a variety of concepts and elements including the system's sensitivity or susceptibility to multiple stressors and the capacity to cope and adapt (IPCC, 2014).

Although livelihoods have continuously adapted to changing environments in the past, climate change is presenting newer challenges at an unprecedented pace and magnitude and increasing local vulnerabilities. Yet, the study of vulnerability in drylands is not given the urgency that it warrants. A common misconception in drylands research in India is that poor people live in drylands and therefore drylands are vulnerable. This leads to an often-misconstrued interchangeable relationship between poverty and vulnerability. Thus, there is a need to better understand and characterise dryland vulnerability in India's arid landscapes.

The United Nations Convention to Combat Desertification (UNCCD) highlights the lack of viable vulnerability assessment methodologies for dryland communities and the vital need to develop a context-specific vulnerability index for drylands (Low, 2013). Reed and Stringer (2015) state that the main challenge is in the development of new scientific insights and recommendations to policymakers on how best to characterise and understand the vulnerability and adaptive capacities of ecosystems (in particular agro-ecosystems) and populations, in regions affected by dryland degradation, including regions newly susceptible to the consequences of climate change. They argue that this will help managing responses and monitoring and evaluating responses.

This is especially significant in the complicated, dynamic, and stratified arid landscapes of India, where characterising socio-ecological system vulnerability becomes especially important in developing evidence-based solutions that work at a local level. An adequate understanding of vulnerability is also of topical interest in India since the United Nations Climate Change Conference in Paris (COP 21). Since 2015, the Government of India's Ministry of Environment, Forests and Climate Change (MoEFCC) has set forth guidelines for all state and district level authorities in India to prepare vulnerability profiles and estimates as a prerequisite for priority approval of adaptation funds under the pilot National Adaptation Fund on Climate Change (NAFCC)[8] (GoI, 2015). The MoEFCC also intends to use the results of national, regional, and local level vulnerability assessments in reporting to the United Nations Framework Convention on Climate Change (UNFCCC) (MoEFCC, 2016).

1.6 Study location: Why Jodhpur, Rajasthan?

The state of Rajasthan which is located in the north-west of India has the largest area undergoing degradation and desertification (approximately 63% of the state's TGA). While the eastern part of Rajasthan is fertile with hills and plains, the rest of the state, especially the west, is arid to hyper-arid, with sandy soils and scrub vegetation (see Figure 1.2). The Aravalli hill ranges, running from north-east to south-west, divide the state approximately into the western arid and eastern semi-arid regions. In India, there are about 2.34 million sq.km of hot desert called 'Thar', which has been called the 'most inhospitable arid zone in the world' (Sinha et al., 1996), and 91% of the Thar desert lies in western Rajasthan. Despite its fragile eco-geomorphology, this region is home to 200 people/sq.km and 160 livestock/ha land (Census of India, 2011). About 60% of these people depend on agriculture for their livelihood and most are directly involved in farming. Nearly half are small or marginal farmers, with cultivation land less than one hectare (ha) (Rathore, 2004). While agricultural productivity has improved due to structural transformations in agriculture, water scarcity continues to be a critical issue.

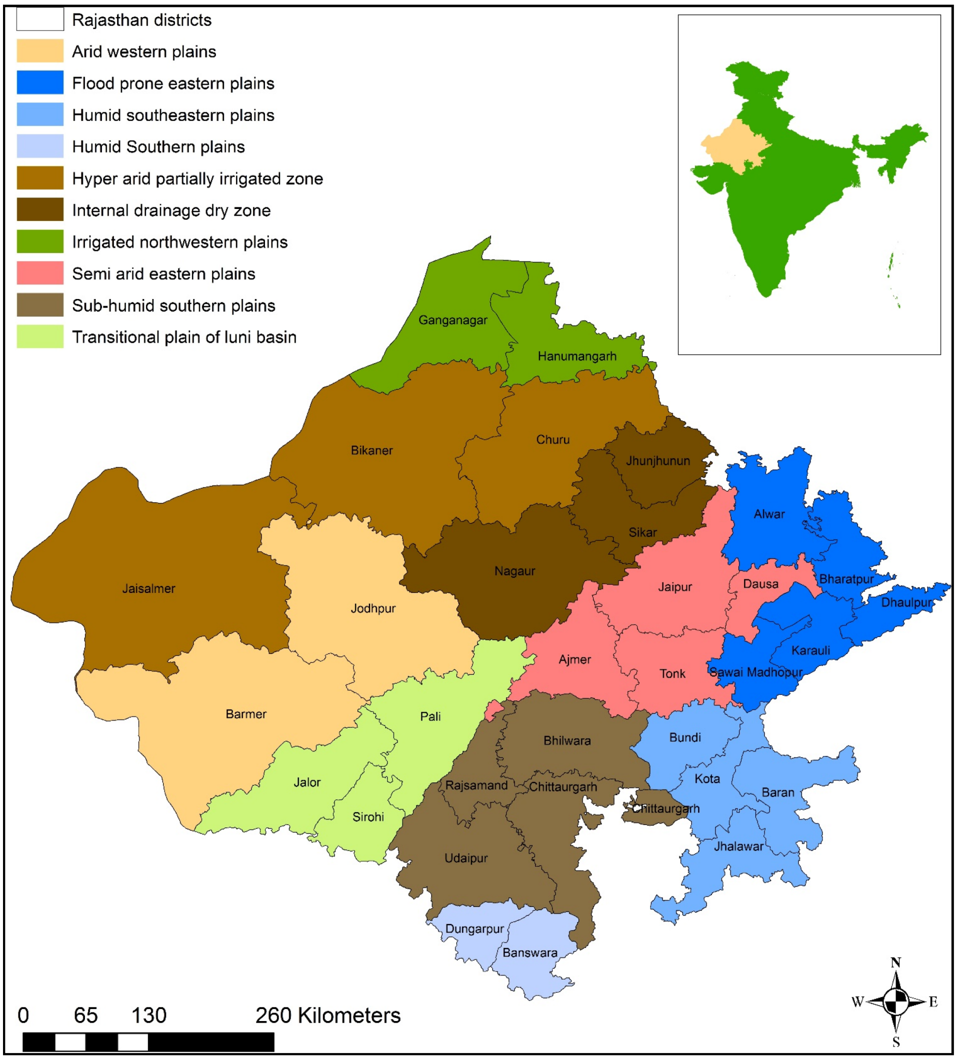
[8] The NAFCC was established in 2015-2016 to help in scaling up of climate change adaptation interventions in accordance with the national and state level action plans.

Rajasthan's rainfall is low and unpredictable and the state has India's lowest surface and groundwater availability (Chinnasamy et al., 2015). Furthermore, climate projections show rainfall will fall in shorter, more intense bursts, and the region is likely to get hotter and drier (Chinnasamy et al., 2015). This would entail more stress on vegetation and increased wind erosion.

Jodhpur is one of the 33 districts of Rajasthan and is located in the arid western plains (see Figure 1.2) of the state. (GoI, 2007). The district of Jodhpur in Rajasthan is representative of typical arid zone problems in India. Jodhpur district has one of the highest percentages of degradation among the dryland districts of India. Amongst India's 646 districts, Jodhpur was stated as the fifth most vulnerable district[9] in terms of the impacts of climate change on agriculture (Rao et al., 2016). Crop productivity of key rain-fed crops such as millets and legumes are comparatively lower than other dryland regions of India. With increasing human and livestock populations that are almost entirely dependent on the land, implications of land degradation are likely to be particularly pervasive in Jodhpur. There are also significantly fewer publications and research reports on the arid zones of Jodhpur. Indeed, important global reports on drylands (i.e. 'Millennium Ecosystem Assessment', 'Global drylands: A UN system-wide response'), have no reference to India's populated arid Thar desert and only make a passing reference to the landscapes and livelihoods of India's drylands (see Safriel and Adeel, 2005; UN, 2011).

[9] Demarcation of districts, sub-districts and villages change often in India. As of Census 2011, India had 640 districts, as of 2016 there are 707 districts in India. At the time of this study, India had 646 districts.

Figure 1.2: Rajasthan state showing its 33 districts and different agro-climatic zones. Inset is the location of Rajasthan state in India



Source: Chinnasamy et al., 2015

1.7 Research objectives and design

The thesis contributes to this critical research area by developing and applying a methodological framework centred on vulnerability for investigating dryland degradation in India's arid landscapes. It does so by not only considering conservation of land resources, but also the adaptability of its ecosystem to adjust to climate variability and risks.

It bridges key gaps in dryland research by using vulnerability as an overarching framework, within which to explore socio-ecological linkages in dryland agro-ecosystems of Jodhpur. Rather than relying solely on quantitative, data-driven understandings of land degradation, this research incorporates perceptions and experiences of those who live in these landscapes. The study draws on a human-centric vulnerability framework, one which places the land manager at the centre, and which interprets vulnerability as an endogenous concept, focussing on system sensitivity (of both land and society) and a lack of adaptive capacity. Vulnerability analysis is conducted using both, a quantitative indicator-based framework and qualitative research. Field research was conducted in 2015-2016 in Jodhpur and through this, vulnerability criteria and indicators developed. Two clusters were selected for study across the district: Cluster I, where agriculture is largely rain-fed and for subsistence, and Cluster II, where agriculture is largely reliant on irrigation and increasingly marketed. Data was collected through a combination of semi-structured household interviews (n=163), focus group discussions (n=4), in-depth interviews (n=10) and observations.

Specifically, the research has three main objectives:

(i) **To understand dryland degradation in arid Jodhpur:** to examine key components influencing status, use patterns, and drivers of land degradation in Jodhpur from the perspective of communities and triangulating their perceptions with secondary data. The research addressed under this objective includes an analysis of the:

- Extent of land degradation in the district of Jodhpur, as estimated by secondary data: *Is dryland degradation a key challenge in the region?*
- Extent of dryland degradation, as perceived by communities in the region: *How do communities within Jodhpur differ in their perceptions of degradation?*
- Significance of climate variability and climate change in the region: *What are the trends in climate variability and climate change? Are community perspectives a good indicator of observed climate trends in the region?*
- Newer climatic trends and interactions with land use and land degradation: *Are communities recognising newer trends in climate, that are not yet visible in observed climate data?*
- Role of institutions: *What is the role of institutions in managing the interactions between dryland degradation and climate variability and change in the region?*

(ii) **To develop a context-driven framework of vulnerability:** to better understand the drivers of vulnerability and consequences on land management in the arid zones of Jodhpur. Research addressed under this objective includes an:

- Exploration of varying disciplines and concepts to enable a holistic assessment of vulnerability: *What is the best way to characterise the vulnerability of the arid dryland agro-ecosystems of Jodhpur?*
- Analysis of the drivers of vulnerability at multiple local scales: *What are the key factors driving vulnerability at the multiple local-scales selected for this study (clusters, villages, households)?*
- Analysis of critical socio-ecological factors shaping vulnerability according to communities: *How can a vulnerability analysis be enhanced by using participatory local*

knowledge? What new knowledge does this provide on characterising vulnerability in Jodhpur's drylands?

(iii) **To provide evidence-based recommendations:** to ensure policies and programmes aimed towards sustainable land management and adaptation planning are better targeted to address the need of India's dynamic arid landscapes and societies. Research addressed under this objective includes an examination of the following:

- Functional relationships between the status and dynamics of dryland degradation and vulnerability: *Which communities are most vulnerable to the combined effects of dryland degradation and climate variability and why?*
- Incorporation of the dynamic nature of vulnerability in targeting communities across the vulnerability spectrum in addressing dryland degradation: *How can vulnerability be incorporated into wider frameworks of addressing dryland degradation by decision makers?*

1.8 Unique contributions of the research

Through addressing these objectives, the research will make the following unique contributions to drylands research; it is motivated by the urgency of the research gaps presented in Section 1.5:

1. Bridge local knowledge and scientific research to better understand the inter-relationships between land use, land degradation, and climate risks in the neglected arid regions of India;
2. Develop a context-driven vulnerability index for the arid drylands of India; through critically exploring definitions and methods in current vulnerability research and by applying a bottom-up approach to vulnerability;
3. Enhance vulnerability concepts through incorporation of characteristics specific to the unique nature of drylands using: (i) community derived sensitivity thresholds (of land and society); (ii) reliability of access and; (iii) sustainability of adaptive capacities. This helps address gaps in the lack of acknowledgement of temporal and spatial complexities in drylands vulnerability research;
4. Illustrate the links between dryland degradation and vulnerability, highlight the significant role played by vulnerability in mediating socio-ecological systems; and
5. Present decision makers in India with recommendations on addressing dryland degradation and vulnerability in the stratified arid zones of Rajasthan.

1.9 Structure of the thesis

The thesis consists of eight chapters, including this introductory chapter. The remainder is structured as follows:

Chapter Two provides an in-depth review of the main study concepts. It begins by detailing the complexities present in current framings of dryland degradation, and the challenges this poses for land governance in different drylands. The evolution of drylands thinking is traced from the initial desertification paradigm to more recent paradigms that emphasise participatory research at the local level. The significance of risk, and in particular the role of vulnerability, is inadequately understood in drylands research. A close examination of the vulnerability literature in the Global South suggests that there is a need to determine the relevance and suitability of current conceptualisations and assessment methods for varying drylands. The aim of this chapter is to establish the current direction of debates on dryland degradation, and to clearly outline how using vulnerability as an integrating concept can contribute to addressing some of the more persistent gaps in this literature.

Chapter Three presents the detailed context for the selected study area. It begins with an introduction to India in the twenty-first century, providing information on India's socio-economic development and agricultural challenges. The chapter then focuses on the state of Rajasthan, highlighting the current state of knowledge on the extent and determinants of land degradation. It introduces the decentralised structure of India's government and the central role played by the state in managing land resources. While discussing Rajasthan's drylands, Jodhpur emerges as an interesting case in which to pursue this research. Analysis will show how the historical and contemporary developments of Jodhpur's rural agro-ecosystems have shaped the present state of agriculture and livelihoods. This chapter provides the context and background for the remainder of the thesis.

Chapter Four presents the research methodology. It begins with an introduction of the epistemological choices in developing a conceptual framework of analysis, where vulnerability is embedded within a socio-ecological system. It presents the research questions and the methods followed in operationalising the conceptual framework, including how dryland degradation is defined and the concepts of vulnerability (sensitivity and adaptive capacity) are assessed. The data collection tools and methods used in the study are described; including sampling strategies in selecting the two clusters for the field study: Cluster I (Shergarh) and Cluster II (Osian). Information is presented on the villages and households chosen within each cluster, their socio-economic and living conditions, geomorphology, local governance structures, and the cultural and religious factors that are important to understand the analysis. A discussion of data analysis and information on data triangulation is also included. Finally, an overview of the challenges and limitations of conducting the research is presented, which include ethical considerations, issues relating to being a female researcher in Rajasthan, and the complexities presented by daily field research.

Chapter Five addresses the first research objective: to understand dryland degradation in arid Jodhpur. It presents a detailed examination of dryland degradation and the interactions with key climate risks in Jodhpur district. The analysis is first conducted using secondary data and meteorological evidence, followed by an analysis of community perspectives. The research examines how communities perceive and communicate the complicated concept of 'dryland degradation'; and whether community perspectives are a good indicator of larger scale trends in climate variability and change in the region. The chapter then provides unique evidence and insights into the synergies and feedback effects between climate risks, land use, and land degradation in the oft-neglected arid zones of India. Finally, it demonstrates, using specific examples, the significant role played by the state in shaping land management strategies since the formation of the state of Rajasthan in 1949.

Chapter Six addresses the second research objective: to develop a context-driven framework of vulnerability. In revisiting the key vulnerability concepts from the literature review, it underscores the importance of using endogenous vulnerability for framing assessments of dryland degradation. The chapter develops and presents a mixed method approach to vulnerability: first, an index - Agriculture and Livelihood Vulnerability Index (AgLiVI) - is developed and the results are presented; this is followed by a qualitative, narrative-driven vulnerability assessment. In using both quantitative and qualitative methods, the analysis draws upon the key strengths of each, while addressing their weaknesses. Finally, a refined framework of vulnerability is proposed that, while keeping with broader concepts of sensitivity and adaptive capacity, also incorporates community-derived understandings of vulnerability. The purpose of the vulnerability assessment is to provide an understanding of the localised endogenous factors that drive vulnerability of agriculture and livelihoods in the two clusters of Jodhpur. Through an analysis of the conditions and responses of the vulnerable households, villages and clusters, this chapter provides an overview of the current aspects of agriculture and livelihoods that contribute to increased sensitivity and lack of adaptive capacity, as well as highlight those attributes that promote resilience.

Chapter Seven addresses the third research objective: to provide evidence-based recommendations. To do so, it clarifies the often-misrepresented relationship between hazards, exposures, and vulnerability and the significance of each in managing the risks posed by dryland degradation. The analysis highlights how responses to risk in Jodhpur, and more broadly in India, focus on eliminating hazards and exposures, with an emphasis on transforming traditional agricultural practices. The chapter brings together findings (from previous chapters) on some of the challenges faced by both researchers and decision makers in addressing the dual challenges of vulnerability and dryland degradation. Using specific case histories from the two clusters, four new typologies of vulnerability are developed which illustrate the interlinkages between vulnerability, land use, and land degradation. The chapter concludes with recommendations for decision makers, and highlights the advantages that vulnerability assessments can provide for understanding the drivers of dryland degradation.

Chapter Eight draws together the main ideas and findings of the thesis and illustrates how the thesis has addressed the research objectives set out above. This chapter highlights the empirical, methodological and conceptual contributions of the research to India and to broader research on dryland degradation and vulnerability in regions of high variability and uncertainty. It also presents final reflections including possible directions for future research.

2. Literature Review

Land degradation is a persistent global problem and researchers are faced with the challenging task of assessing the extent, trends, drivers, and consequences at multiple spatial and temporal scales and across regions. There continue to be wide-ranging debates surrounding the definition of land degradation, which have translated to methodological inconsistencies in measurements of the phenomenon. In this chapter, the evolution of key concepts, theories, and methods developed to better understand land degradation in drylands is traced. This includes exploration of the less understood concept of desertification introduced in the early half of the twentieth century to present shifts in perspective, where the focus is on better diagnosing vulnerability and risk in drylands. The discussions in this chapter will demonstrate why the recent focus on the inherent vulnerability of dryland socio-ecological systems is a step in the right direction. One of the key contributions of this chapter is drawing together bodies of literature on 'dryland degradation' and 'socio-ecological vulnerability'. These concepts have largely been researched independently of each other. Yet, there are many convergences in their constituent principles that are likely to benefit drylands research and policy development.

The chapter is structured as follows:

- Section 2.1 begins with an overview of the state of knowledge on land degradation in drylands. The section traces shifting theories of the causes of land degradation from attributing degradation to predominantly anthropogenic factors to integrating anthropogenic and climatic factors;
- Section 2.2 focuses on the evolving paradigms of dryland development, highlighting key principles of the desertification and resilience paradigms, followed by a discussion of newer conceptualisations such as the dryland development paradigm and the alternative livelihoods paradigm among others;
- Section 2.3 draws on key critiques of previous dryland paradigms, highlighting the status and gaps in current drylands research;
- Section 2.4 introduces vulnerability as a central concept in conceptualisation of dryland socio-ecological systems and traces the evolution of vulnerability research from its origins in Sen's (1981) theory of entitlements to its current usage, rooted in the strengths of climate science;
- Section 2.5 introduces the diverse set of methods used to assess vulnerability, highlighting some of the main conceptual, methodological, and operational challenges of assessing vulnerability;
- Section 2.6 introduces the limited vulnerability assessments conducted within dryland agro-ecosystems, highlighting the key strengths and limitations of existing research; and

- Section 2.7 concludes highlighting the scientific knowledge gaps.

2.1 Defining and framing dryland degradation

Land degradation is a term that is widely used with varying definitions (Safriel, 2007). The most commonly used definition is that of the United Nations Convention to Combat Desertification (UNCCD). Land is defined as "a terrestrial bio-productive system that comprises soil, vegetation, human settlements, and the ecological and hydrological processes that operate within the system" (UNCCD, 1994). Land degradation is defined as "a reduction or loss of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns" (ibid.).

The Millennium Ecosystem Assessment (MEA) simplifies the UNCCD's definition; land is defined as the "terrestrial ecosystem" and land degradation as "a persistent reduction of the biological and economic productivity of terrestrial ecosystems" (MEA, 2005: 1). This definition approaches degradation through the lens of a reduction of ecosystem services provided by the land, in particular the primary production service[10] (Safriel & Adeel, 2005). Ecosystem services are defined as functions of and processes supplied by ecosystems and valued by humans, such as supporting services, regulating services, provisioning services, and cultural services (MEA, 2005). While the maintenance of basic ecosystem services can relate both to human and non-human uses (Reed & Stringer, 2016), definitions of land degradation are closely tied in with the social context of human benefit, derived from the use of ecosystems by people (Blaikie & Brookfield, 1987; Safriel, 2007).

While land degradation can occur in all agro-ecological zones, in this thesis the focus is on land degradation in drylands. Degradation in drylands continues to be widely associated with the complex and inadequately understood process known as desertification (Mortimore, 2009). Definitions of desertification vary and Stiles (1995) reported at the time that there have been more than one hundred definitions without any consensus on the concept of the phenomenon. The term desertification was introduced around the 1920s, but significant research and controversies have surrounded it since (Mortimore, 2009). The term desertification first arose due to the proximity of many drylands to deserts, generating concern about desert encroachment (ibid.). While the term was introduced in the 1920s, the concept became established in the aftermath of the great Sahelian drought of 1968-74. Decades of extended droughts, loss of crops and livestock, and subsequent famines in the Sahel led to an urgency to

[10] Primary production service or productivity here refers to the key environmental services provided by the land on which much of human well-being depends.

attribute a cause to these events. As Toulmin and Brock (2016) identify, this led to the top-down framing of desertification as an irreversible crisis, allowing authoritarian interventions and attribution of blame to Sahelian farmers and pastoralists. Human-led mismanagement of the land was cited as the primary reason behind 'encroaching deserts' and poverty and ignorance cited as reasons for the mismanagement (Mortimore, 2009; Toulmin & Brock, 2016).

During this period, there was also a lack of a productive relationship between science and public policy, which made it difficult to agree on common conceptualisations and methodologies to explain the causes and address the consequences of desertification. The formation of the UN Conference on Desertification in the 1970's (UNCOD) and later the UNCCD in 1992[11] (Sen & Kar, 1993) also led to institutionalisation of this concept of desertification (Toulmin & Brock, 2016). The UNCCD developed the most commonly accepted definition for desertification, "Land degradation in arid, semi-arid and sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1994).

Research has since highlighted the inadequacy of the concept of desertification in explaining social and environmental change in drylands (Peters et al., 2015; Reynolds & Stafford Smith, 2002). For instance, recent advances in science have effectively resolved that the changes in the Sahel in the 1960s-1990s were likely the most dramatic example of climate variability in the 20th century and not a result of poor environmental management and overpopulation as thought at the time (Behnke & Mortimore., 2016; Kucharski et al., 2013). Much contentious debate continues on whether desertification, as it is commonly understood (primarily human-led and largely irreversible), distorts views on understanding socio-ecological systems[12], their interactions, and their resilience in drylands (Bestelmeyer et al., 2015; Nicholson et al., 1998; Prince et al., 2007). To resolve this dilemma, Behnke and Mortimore (2016) are of the view that instead of attempting to analytically utilise and map desertification, the focus should shift to better defining and operationalising the concept of dryland degradation.

Indeed, a more valuable approach must be one that accounts for the 'complexity' that is inherent within dryland socio-ecological systems. Rutherford and Powrie (2010: 692) highlight that the emphasis in definitions of degradation needs to be on the 'complexity' component - "Reduction or loss of the biological or economic productivity and '*complexity'* of terrestrial ecosystems". Thus, dryland degradation is best studied as a synthesis of the complex

[11] Due to a perceived ineffectiveness of the UNCODs Plan of Action to Combat Desertification (PACT), it was replaced by the UNCCD at the Rio Conference (Earth Summit) in 1992.

[12] Socio-ecological systems (SESs) as defined by Ostrom (2009); and subsequently enhanced by others including Hinkel (2014) and McGinnis and Ostrom (2014) are composed of multiple subsystems and internal variables within these subsystems at multiple levels. In a complex SES, subsystem such as a resource system (e.g. a coastal fishery), resource units (lobsters), users (fishers), and governance systems (organisations and rules that govern fishing on that coast) are relatively separable but interact to produce outcomes at the SES level, which in turn feedback to affect these subsystems and their components, as well other larger or smaller SESs.

interactions between climate, ecosystems, and social systems within inherently dynamic environments (Behnke & Mortimore, 2016). This conceptualisation of dryland degradation has been referred to in drylands research as reflective of the more interpretative and post-modern epistemologies required to capture complex understandings of socio-ecological systems interactions (Reed & Stringer, 2016; Tarrasón et al., 2016).

The next section traces some of the paradigms that have led to the current state of knowledge on dryland degradation, and draws attention to the strengths and weaknesses of each paradigm.

2.2 Evolving paradigms of dryland development

As discussed above, many authors have suggested that the significance of human impacts were largely overemphasised through the Sahelian drought of the late 1960s and 1970s. During this time, the inclusion of humans in discussions of land degradation, "provoked a veritable sandstorm of literature" (Vogel & Smith, 2002: 151). Vogel and Smith (2002) categorise five broad theoretical approaches upon which a majority of dryland studies were structured:

- **Classic approach**: Assumes the extent of solutions to the land degradation problem are clear; and that the constraint lies in lack of cooperation from communities. It adopts the idea that dryland degradation is a problem purely of inadequate implementation of suitable management strategies.
- **Populist approach**: Critics of the classic approach were of the opinion that communities were not the problem but rather the solution to dryland degradation. The populist approach was defined by the authors as "a people-centric, bottom-up, and political-radical approach" to land degradation that includes among other elements, issues of land tenure, distribution, local empowerment, and security. These ideas are central to the work of several developmental agencies and NGOs (ibid.).
- **Neo-liberal approach**: Identifies the significance of better understanding human behaviour if dryland degradation is to be resolved. Biot et al., (1996) highlight that a number of counter-solutions and technologies exist to evaluate, monitor and reduce impacts of dryland degradation. For them the problem lies in designing incentives that induce the adoption of these technologies (ibid.).
- **Neo-Malthusian approach**: Presents land degradation as the lack of balance between the carrying capacity of land and the human populations that depend on it. This approach assumes increasing populations put extra pressure on the land leading to problems of dryland degradation. Ideas of over-grazing, intensification, deforestation are all assumed to be problems of this nexus between people and their environment.
- **Political ecology approach**: Blaikie and Brookfield (1987) critiqued the population pressure ideas of the neo-Malthusian approach, highlighting that degradation can be

viewed from varying perspectives and social relations under which a land manager functions, including marginality (political, economic, ecological). Political ecology assumes a close link between environment and development, important for social scientific thinking. The approach highlights that there are many diverse ways in which environmental changes may or may not be experienced as degradation, depending in part on the use to which the land is put (Jones, 2008).

The given theories have underpinned most studies on human-environment interactions in drylands since the 1970s and continue to influence views on the use of the natural resource base. These have led to the development of paradigms such as the 'desertification paradigm', the 'resilience paradigm', and, the 'dryland development paradigm', which provide for established frameworks within which to understand dryland degradation.

2.2.1 The 'Desertification' Paradigm

The desertification paradigm holds that dryland ecosystems that are in a stable equilibrium state are pushed into a transition to a new disequilibrium state, of much lower levels of service provision, largely due to human mismanagement (Safriel & Adeel, 2005). This means that since soil degradation and vegetation degradation are linked to increased aridity as part of a negative feedback loop, desertification is largely irreversible (Cleaver & Schreiber, 1994). Desertification and increasing poverty are linked together and considered to be a result of a chain of destructive anthropogenic drivers (Safriel & Adeel, 2008).

Research over the past century has demonstrated that the processes leading to dryland degradation are much more complex and can vary significantly by context. Dryland researchers emphasise that rather than a stable equilibrium, a given dryland ecosystem is better understood as a state of disequilibrium, since its productivity levels (or service provision) are dependent on variable climate (Mortimore, 2009). Further, despite this focus on human behaviours and the downward spiral they are said to cause in leading to desertification, the principles of the desertification paradigm are largely ignorant of the complexity of the social sciences. The desertification paradigm is instead heavily rooted in the environmental sciences through its focus on the reduction of soil fertility. Swift (1999: 12) highlights, "Soil science has been brilliantly informed by reductionist physics and chemistry, poorly informed by biology, ecology and geography and largely uninformed by the social sciences". The principles of the desertification paradigm are therefore not sufficiently robust to explain the processes surrounding dryland degradation (Peters et al., 2015).

An addendum to the Desertification Paradigm is the development of earth satellite data, geographic information systems (GIS), and remote-sensing technology which have all provided fresh perspectives through monitoring the extent and spread of the key processes leading to dryland degradation (Mortimore, 2009). Importantly, the development of satellite data has shown the dominant influence of climate change and rainfall variability on drylands, calling into question earlier notions emphasising human mismanagement as the primary cause of dryland degradation (ibid.). Such studies are reliant on indicators including Normalised Difference Vegetation Index (NDVI), Net Primary Productivity (NPP), Rainfall Use Efficiency (RUE), and Residual Trend Analysis (RESTREND). The FAO's Land Degradation Assessment in Drylands (LADA) project, for instance, considers ten parameters to be assessed and then aggregated into one single indicator (Nkonya et al., 2011). The soil health indicator, for example, includes for an aggregation of soil depth, structure, texture, sodicity among other indicators[13].

A key critique of using methods that are heavily reliant on mapping techniques is that in attempting to aggregate complex information, their usability on the ground can become limited. The NDVI for instance, is calculated from remotely sensed reflection of vegetation surfaces and gives information on density, condition, and health of photo-synthetically active vegetation (Nkonya et al., 2011). Many semi-arid and arid environments tend to have a higher cover of bare ground and exposed rock, where light from soil surface has been known to influence NDVI values, putting into question its robustness for these regions (Sanchez-Mejia et al., 2014). Furthermore, due to the nature of satellite data, a majority of the indicators mapped are biophysical in nature. Certain socio-economic indicators such as population density and livestock pressure (number and density) are also assessed as part of global soil monitoring projects such as the Natural Resources Conservation Service (USDA-NRCS) and Global Land Degradation Information System (GLADIS). These indicators provide valuable insights into broader-scale (e.g. global to regional scales) implications of the collective impact of human settlement development and the direction of potential future growth on the state of the land (Nkonya et al., 2011).

However, the crucial role of complexities in governing the state of resources, as discussed in Section 2.1, is often lost at these larger scales of assessment. If the results of these studies are to be used as a basis for generating scientific and policy prescriptions, the analysis must be expanded with information and data that reflects field level complexities. This can include information on the biophysical parameters, such as documentation of exposed ground in arid lands or the quality of vegetation (invasive plant species vs indigenous plant species), and also

[13] Using GIS, the LADA project uses the Driving Force-Pressure-State–Impact-Response framework (DPSIR) to assess land degradation at local, national and global scales (FAO, 2007). The DPSIR framework was developed for the European Environment Agency (EEA) for Integrated Environment Assessment. It focuses on a chain of causal links starting with 'driving forces' through 'pressures' to 'states' and 'impacts' on ecosystems, human health and functions, eventually leading to political 'responses' (prioritisation, target setting, policies)

the social parameters, such as inter-household relationships, land tenure, and the role of women, which are all crucial to land management. However, given the scale and methods used in remote-sensing studies, it is difficult to assimilate the more nuanced field level perspectives of the most vulnerable groups, which dryland researchers have identified as crucial (Reed et al., 2008; Stafford Smith, 2016). This therefore remains one of the key limitations of assessment methodologies that have arisen out of the desertification paradigm.

Overall, the desertification paradigm puts a heavy focus on human agency as a key driver of degradation and it prioritises scientific (as opposed to local) knowledge, emphasised through global and regional scale monitoring and measuring of the extent of degradation. However, as Mortimore (2016) identified, it leads to top-down recommendations for interventions that look to transform current land use patterns and local livelihoods. More recently, some desertification studies provide for better convergences between the science of desertification and local practice (e.g. Winslow et al., 2011). However, the narrower scope of the older interpretations has become sufficiently embedded and institutionalised, and such convergences are sporadic.

2.2.2 The Resilience Paradigm

The resilience paradigm was borne out of the need to address the conceptual weaknesses of the desertification paradigm. This paradigm recognises that dryland ecosystems are characteristically at a disequilibrium due to their surrounding climate. Thus, the resilience paradigm holds that "the chain of events that leads to desertification and the chain-reaction cycle of reduced ecosystem productivity and poverty are far from inevitable" (Safriel & Adeel, 2005: 646). The authors indicate that there is increasing evidence that these negative feedback loops need not always occur. Mortimore (2009) states that the capacity of a dryland ecosystem to maintain its functional integrity while adjusting to variable drivers justifies describing it in ecological terms as unstable yet resilient.

Another key aspect of the resilience paradigm is the use of suitable technologies and farming techniques to address the impacts of land degradation. Communities develop their own strategies to adapt to changing climate patterns based on collective knowledge acquired through past experiences (Kattumuri et al., 2017; Patnaik, 2010). For instance, changing cropping patterns and crop diversification is practised by many farmers in drylands. The work of Biot et al. (1996) highlighted that suitable technologies also exist to manage the extent of land degradation, such as innovative soil and water conservation techniques and the increased use of mineral fertilizers. For instance, in India, considerable progress has been made in the genetic dissection of flowering times, inflorescence architecture, and temperature and drought tolerance in plant systems (Venkateswarulu & Shanker, 2009). Thus, while drought and irregular rainfall patterns affect agro-diversity in drylands causing significant distress to local communities, advanced genomics provides the potential for vegetation recovery.

The resilience paradigm offers a more flexible approach that incorporates multiple sustainable development pathways (Safriel & Adeel, 2008) when compared with the desertification paradigm. The principles of the resilience paradigm do not however take into consideration the inevitability of continued and increasing pressure on dryland resources, which are expected to be further exacerbated by a global increase in the demand for agricultural land. Safriel and Adeel (2008) also argue that technological ingenuity and adaptive capacity will be exhausted at some threshold level of resource use. For instance, while advanced genomics can help vegetation patterns improve after certain climatic shocks, they are unlikely to have the same species composition as before. There is also sufficient evidence that the use of technology-intensive farming has not always had positive environmental and social consequences, with large areas excluded from the productivity gains offered by the technological revolutions (Swaminathan, 2017).

One of the more systematic approaches developed in response to the criticisms of the previous two paradigms is the Dryland Development Paradigm (DDP), discussed below.

2.2.3 Dryland Development Paradigm (DDP)

The Dryland Development Paradigm (DDP) offers a conceptual advancement in better exploring dryland degradation (Reynolds & Stafford Smith, 2002). The DDP addresses the livelihoods of human populations in drylands via the study of coupled human-ecological (H-E) systems. Key principles of the DDP focus on the dynamic nature of coupled H-E systems, highlighting the complex interactions between biophysical and social sub-systems. The DDP differentiates variables into slow and fast variables. 'Slow' variables are determined by long-term parameters (e.g. soil fertility, household capital wealth). 'Fast' variables are short-term parameters (e.g. crop yields, rainfall patterns, change in policy). The DDP holds that fast variables generate 'noise' and overpower the more important fundamental changes brought on by slow variables. The DDP emphasises that thresholds exist for slow variables beyond which systems can move into new states. Thresholds can be actual or potential regime shifts in the ecological, social, economic, or political domains (Maestre et al., 2006; Reynolds et al., 2007).

In devising the DDP, Reynolds et al., (2007) use the term - 'drylands syndrome' (ds). It refers to drylands as regions with the following characteristics: (i) high variability (ds1); (ii) low soil fertility (ds2); (iii) sparse populations (ds3); (iv) remoteness from markets (ds4); and (v) distant voice (ds5) from centres and priorities of decision makers (ibid.). Examined in detail, these characteristics are unlikely to hold for all drylands. For instance, the drylands of India are heavily populated regions, some of which are located very close to markets and centres of power in the country.

Criticisms of the DDP: Over the past decade, a series of studies have sought to apply the DDP (Reynolds et al. 2007a; Lambin et al., 2009; Stafford Smith et al., 2009; and Maestre et al., 2006). While the above studies indicate that the DDP offers an important development, its concept of 'slow' and 'fast' variables of degradation have not been extensively adopted. The authors themselves conducted a review of the impact of the DDP and stated that it has not been universally adopted nor have all users found it valuable (Stafford Smith et al., 2007).

Whitfield and Reed (2012) critique the DDP for its focus on the opinions of social scientists while not allowing for sufficient stakeholder participation and incorporation of local knowledge. Grainger (2007) mentions the patchy treatment of uncertainty (high spatial and temporal variability), which in his opinion is an inevitable consequence of the complexity of human-environment systems in drylands. The lack of clarity on how to incorporate climate change is also an important gap of the DDP. Mobility and migration are other features that are not prominent in the DDP, but vital to customary social coping mechanisms, e.g. by pastoralists (Bradley & Grainger, 2004). Furthermore, in dryland rural agro-ecosystems, 'slow' variables, as defined by the DDP, can also be subject to rapid change like the fast variables. For instance, household wealth (categorised as a slow variable) has the ability to change as quickly as that of fast variables such as rainfall variability (and often in tandem).

2.2.4 Other significant research

In addition to the DDP, there are other frameworks developed by authors to better understand dryland degradation. The **Dryland Livelihood Paradigm** introduced by Safriel and Adeel (2008) shows that there is an alternative to both the desertification pathway (of irreversibility) and the resilience pathway (where despite innovations, pressure on finite resources remains high). The authors show that a third pathway is available, where people can direct their ingenuity and adaptive capacity to developing non-degrading alternative livelihoods. The authors argue for alternative livelihoods, skills for which already exist in dryland communities (such as hand weaving and pottery), that provide for economic stability while reducing pressure on land resources. While potentially an interesting framework, there remains uncertainty regarding addressing the root causes of the problems that drive the need for alternative livelihoods in the first place. Furthermore, global demand for food and agricultural land will likely mean that while dryland farmers seek alternative livelihoods, it is unlikely that the land itself can be left uncultivated for long. There is evidence from the drylands of Africa that shows that land left uncultivated by local farmers is often taken over by intensive, larger-scale farming, which are far more likely to exacerbate patterns of degradation (Arezki et al., 2012).

Other frameworks with the potential to examine dryland degradation include the work of Gunderson and Holling (2002), who suggest the use of 'Panarchy' as a conceptual framework to study transformation in human and natural systems. The authors study how economic growth and human development depend on ecosystems and institutions, and also use the concept of slow and fast variables to show interactions within a socio-ecological system. While 'Panarchy' has been applied by authors in different socio-ecological settings (e.g Soane et al., 2012), its empirical value in assessments of dryland degradation is yet to be established.

2.2.5 Participatory frameworks

More recently, a new wave of participatory methodologies that incorporate both scientific and local knowledge have been brought to focus in drylands research. The importance of primary research in investigating the processes of dryland degradation was emphasised by dryland researchers from as early as the 1970s and 1980s (Swift, 1999). Sufficient evidence exists on the value added by indigenous and local knowledge systems in adaptation to climate change and sustainable resource management, especially in drylands (Tengo et al., 2017). However, local knowledge systems and the risk management practices that arise from them continue to be used sparingly in global sustainability research.

Berkes et al. (2000) offer some insights into this wider history of exclusion. The authors highlight that indigenous practices in resource management are often difficult to identify and generalise. For instance, the embedded nature of traditional resource management practices mean that some social groups document it, while others may not. Similarly, practices may vary from one time period to another. Thus, many traditional practices are difficult to recognise and document (even when spending significant time with the communities in question) (ibid.). Furthermore, indigenous knowledge systems stem from inherent social mechanisms, such as local customs, culture, power relations, gender, and religious and spiritual constructs among others (Colding and Folke, 1997). All of these cross-cutting themes lead to the generation of local knowledge within the constructs of the society within which they are embedded (Berkes et al., 2000). Understandably, many of these themes fall outside the largely ecological realm of understanding dryland degradation. This is largely due to the context specific and complex nature of translating findings on local indigenous knowledge and related social constructs into broader research and policy processes.

However, authors including Chambers and Conway (1992), Gliessman et al. (1981), Gupta (1992) have long argued that the heterogeneity present within people and landscapes are diverse enough that there will be important lessons to be learnt and disseminated. Agrawal (1995) is of the view that the problem in translating indigenous knowledge systems to wider research lies not in gathering and understanding the information, but rather in the dichotomous conceptualisations of indigenous vs. scientific research. The varying interactions and feedback effects present within ecosystems in the Anthropocene need the support of multiple knowledge systems (ibid.). Importantly, there is sufficient evidence to show that understanding indigenous knowledge systems and local power relations have contributed significantly to better governance structures (IPCC, 2014).

These debates continue and recent discussions are focused on bridging different knowledge systems to enhance the global governance of resources (Whitfield et al. 2014; Rathwell et al., 2015). Tengo et al. (2017) highlight that one of the key remaining gaps is that methodologies and tools that consistently enable engagement towards useable knowledge of local communities, are not yet available.

Within drylands research, recent studies seek to offer conceptual and methodological solutions to the varying challenges of drylands environmental assessment from a socio-ecological perspective (Fraser et al., 2010; Nkonya et al., 2011; Reed et al., 2011; Salvati & Zitti, 2009; Stringer & Reed, 2007; Tarrasón et al., 2016; Thomas et al., 2014; Twyman et al., 2011; Whitfield & Reed, 2012). Noting this shift in methods to more participatory research, Whitfield and Reed (2012) emphasise three key conceptual pillars that should form the basis for such research:

(1) Drylands are political, cultural and economic systems as well as socio-ecological systems;
(2) Drylands are complex and resilient systems; and
(3) Drylands are temporally-embedded systems i.e. the history of a dryland system makes an important contribution to its contemporary context.

The authors highlight that the focus needs to be on conceptualising a dryland ecosystem first, prior to carrying out an entire environmental assessment on it (ibid.). These studies aim to address the inherent complexities of socio-ecological systems in drylands. The causes of land degradation are hypothesised to involve regionally distinct mixtures of key socio-economic and biophysical factors that may act directly or indirectly, rather than single factors (Thomas, 2008b). As these frameworks gradually translate into practice, they are likely to provide newer insights into the age-old problem of defining the functionalities of drylands and the various facets surrounding dryland degradation. One of the key goals of this thesis is to contribute to this growing body of research. A summary of the important frameworks discussed thus far are provided in Table 2.1.

Having discussed the current state of research in conceptualising dryland degradation, it is important to take stock and highlight some of the persistent gaps in knowledge that every subsequent paradigm has aimed to address, albeit to different levels of success.

Table 2.1: Key characteristics of dryland frameworks

Paradigms of dryland development	Studies	Focus	Key components	Key drawbacks
Desertification Paradigm	Cleaver and Schreiber 1994; LADA project, 2004.	Rooted in environmental sciences i.e. biological productivity, soil health & rainfall parameters	Desertification is practically irreversible, and its inevitability increases with aridity (Malthusian) Focus of a lot of remote sensing projects	- Ecosystems are not at equilibrium & can recoup - Sciences that deal with human behaviour have been largely ignored
Resilience Paradigm	Biot et al 1996; Scoones 2009; Niemeijer and Mazzucato 2002	Resilience - Dryland ecosystems are unstable yet resilient	Technology, new markets and management practices will help maintain functional integrity	- Does not acknowledge that ingenuity and adaptive capacity would be exhausted at some threshold level of resource use - Ignores drivers for induced innovation
Dryland Development Paradigm	Lambin et al. 2006; Reynolds et al. 2007; Stafford Smith et al. 2007; Maestre et al. 2006	Human-environment systems as coupled, dynamic and co-adapting Scientific and contextual knowledge	Cross-scale conceptual holism Concept of slow (long-term) & fast (short-term) degrading variables	- Slow variables can degrade like fast variables - Patchy treatment of uncertainty - Too much focus on qualitative knowledge of social scientists
Dryland Livelihood Programme	Safriel & Adeel 2008	Adoption of 'alternative livelihoods' as a facet of the DDP	Alternate livelihoods provide for economic stability while reducing pressure on land resources.	- Not a sustainable long-term option - Potential to uproot farmers
Participatory frameworks	Whitfield and Reed, 2011; Fraser et al, 2011; Sallu et al. 2010; Doughill et al. 2010	Drylands as complex socio-ecological systems that are temporally embedded and resilient	Focus on understanding the dryland system first Participatory, focus on local scale	- Local scale-dependent - Fewer published studies to draw upon due to qualitative nature of much of the work

Source: Collated from various sources (included in table)

2.3 Status and gaps in drylands research

In reviewing dryland literature thus far, despite research visualising a greater role for socio-economic variables surrounding dryland degradation, there has been a reluctance to move away from a land evaluation approach where mostly biophysical factors are assessed (Peters et al., 2015). Imeson (2012) is of the view that a key challenge with the initial desertification paradigm, and the ensuing monitoring techniques that have arisen from it, is that new scientific innovations that were made in the 1990s until about 2005, when new paradigms were developed and tested, were not followed up. For example, many soil scientists still use methodologies that employ models to predict or combat erosion that are basically a development of the Universal Soil loss equation (USLE) developed in the 1970s. Bruil and Gubbels (2013) and Warren (2002) point out similar critiques of purely statistical evaluations using model developers' notions of what degradation means to land users rather than the inherent or potential utility. This is important because it leads to land management solutions that are essentially technological fixes, without adequate attention given to the socio-political context within which these fixes are applied (Safriel, 2009).

The most likely reason for this is that it is a challenging task to expect universal perspectives or agreements of the 'value' and 'use capability' of land. As discussed in the previous section, this has led to many authors calling for a shift in perspective in drylands research - from global to local - incorporating the spatial, temporal, economic, environmental, and cultural context within which degradation occurs (Mortimore, 2009; Stringer & Reed, 2007; Twyman et al., 2011; Warren, 2002). At a smaller scale these value judgements, although still difficult, are likely to be a lot more practical.

Research has revealed the need for a framework to understand socio-ecological system interactions as a way to better adapt with changing land potential (Bisaro et al., 2014; Blaikie & Brookfield, 1987; Sietz, 2011; Stafford Smith, 2016; Verstraete et al., 2009). Much of the integrated socio-ecological systems research has resulted in a 'hierarchical relationship' between human and physical components, with one providing the initial and boundary conditions for the other to do its work (Demeritt, 2009). Hochstrasser et al., (2014: 41) highlight "In this all too frequent hierarchical mode of investigation, identification and examination of reciprocal feedbacks between physical processes and human activities are limited or absent". A number of existing frameworks such as the Resilience Paradigm, the DDP, and the alternate livelihoods approach have moved the discourse forward. Recent studies aim to conceptualise societies as complex socio-ecological systems (Peters et al., 2015; Twyman et al., 2011; Whitfield & Reed, 2012). However, they are yet to be extensively adopted. Reed and Stringer (2016) find that the mainstreaming of participatory research approaches still lacks adequate emphasis in drylands research.

Of crucial significance is the lack of consideration given to risk in drylands, in both scientific and participatory frameworks of dryland degradation. When natural resources are degraded, primary ecosystem functions are degraded, which in turn generates high risks for the human populations and biodiversity that depend on these very ecosystem functions (Ekins, 2003; Sietz, 2011). These risks will be exacerbated by climate change, rising populations, and growing inequalities. A key element of a systematic assessment of risk involves understanding vulnerability. Risk is triggered when a vulnerable socio-ecological system is exposed to a particular hazard (e.g. climatic) (IPCC, 2014). In dryland agro-ecosystems, socio-ecological systems have traditionally been able to cope with changing land potential. Externalities (e.g. intensifying climate variability and projected climate change) are likely to add further pressure on existing conditions (Thomas, 2008b). There is evidence from some drylands that traditional coping patterns are not proving sufficient due to newer and unfamiliar climatic conditions, that are pushing some farmers towards distress coping strategies (Kattumuri et al., 2017).

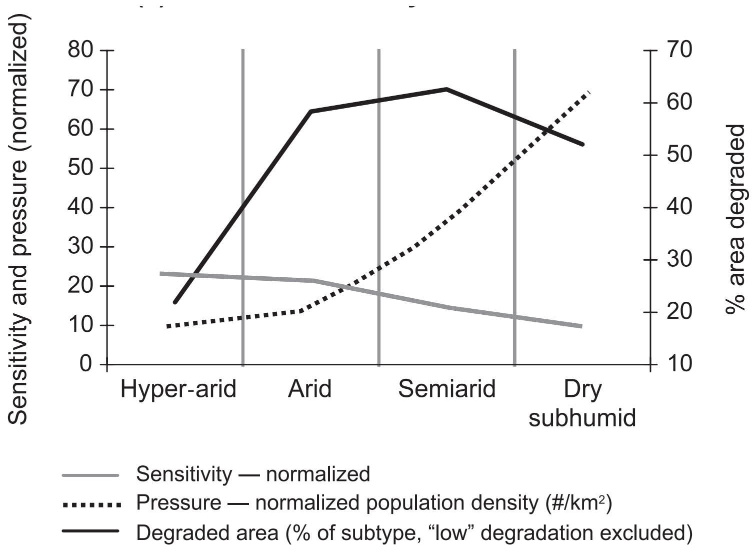
Therefore, an assessment of socio-ecological system vulnerability is an essential first step to understanding the inherent risks in dryland agro-ecosystems that are prone to degradation. Vulnerability, which is embedded within socio-ecological systems, is often expressed through land degradation (as both a cause and consequence). This aspect will be explored in detail in later chapters. The following sections will highlight the growing need to focus on vulnerability in drylands research.

2.4 Approaching an Old Problem through New Lenses: Conceptualising human-environment interactions through the lens of vulnerability

Vulnerability in its very essence indicates susceptibility of a system (anthropogenic or natural) to harm (a range of given stressors) (Sietz, 2011). It refers to the relationship between human-social and/or socio-ecological systems and the extent to which they can be impacted by multiple stressors (Eakin & Luers, 2006). The stresses or perturbations could be gradual (e.g. soil erosion, excessive ploughing) or sudden (e.g. drought, excessive rainfall event), internal (e.g. health-related concerns, loss of assets) or external (e.g. change in land tenure policy).

The significance of vulnerability to the discourse on land degradation is not given the urgency it warrants. Drylands are exceptionally vulnerable due to their low soil fertility, inherently variable climate, and low agricultural productivity, which are projected to worsen in the years to come (Sietz et al., 2017). Figure 2.1 shows the effect of sensitivity[14] and anthropogenic pressure along the aridity gradient[15] of the four dryland zones of the world. It illustrates that high sensitivity can be found in both the arid and semi-arid drylands and in the transition between the two, where there exists a combination of high resource degradation, medium anthropogenic pressure, and medium sensitivity (Safriel & Adeel, 2005).

Figure 2.1: Effect of sensitivity and pressure in drylands



Source: Safriel and Adeel (2005)

Recent research has identified the need to bring vulnerability to the forefront of drylands research. Reed and Stringer (2016) highlighted that if the effects of land degradation, climate change, and their various feedbacks on a given ecosystem or human population are to be addressed, it is necessary to understand vulnerability to the drivers of change. Since 2013, reports by organisations such as the UN and the IIED have also highlighted the importance of addressing vulnerability and building on the existing adaptive capacity of dryland systems, if goals such as land degradation neutrality are to be met (Hesse et al., 2013; Low, 2013; Reid et al., 2015).

While diagnosing vulnerability in drylands is yet to be adequately researched, vulnerability in itself is a concept that has been conceived of in diverse ways in different research streams (Miller et al., 2010). While the sheer volume of literature on vulnerability helps lay a strong and robust theoretical foundation for this research, it also brings with it complications. As many authors have identified, vulnerability is essentially a simple concept in practice;

[14] The authors define sensitivity as the susceptibility of the system to destabilise – i.e. sensitivity of dryland ecosystems to human impact increases with aridity – a little human pressure may not destabilise a dry sub-humid ecosystem but will affect productivity of a semi-arid or arid ecosystem (Safriel and Adeel, 2005).

[15] As discussed in Chapter One, drylands have an increasing aridity gradient from sub-humid (lowest aridity), semi-arid, arid and hyper-arid (highest aridity).

conceptualisations have however been inundated with overlapping, unclear definitions from varying epistemological positions (Adger, 2006; Alwang et al., 2001; Smit & Wandel, 2006). Thus, before addressing vulnerability in drylands literature, a discussion of existing vulnerability concepts and their evolution will prove valuable due to its central place in this research. The following sections will discuss key characterisations of vulnerability, drawing on elements developed by the IPCC and other significant publications and finally relating them back to vulnerability research in drylands.

2.4.1 An archaeology of vulnerability conceptualisations

The evolution in research on vulnerability is a good indication of the progression of contemporary global developmental issues. For example, in the early 1980s when economic growth and poverty alleviation were at the top of policy agendas, theories of vulnerability were heavily contingent on the principles of economic development, using ideas of entitlement and social development. Since the late 1990s, climate change has been at the forefront of research in the field of vulnerability. The evolution of vulnerability conceptualisations to the present day are described below[16].

First dimension – growth and poverty alleviation

The **theory of entitlements** as developed by Sen (1981) within the field of development economics was a very influential basis for studying vulnerability. It emphasised the significance of social constructs in influencing the extent of the impact of hunger and famines. The approach shifted the analytical focus away from the availability of food, the Malthusian logic of the population-food nexus and on to the inability of groups of people to properly manage and distribute food (Devereux, 2001). People's entitlements (goods and services) were viewed a function of their social, economic, political and institutional conditions. While the approach has been debated extensively, mostly for its ambiguity in understanding entitlements, it provided an important basis for investigating vulnerability as a socially driven process (Vogel & Smith 2002; Geest & Dietz 2004)

Research by Chambers (1983) introduced the term 'vulnerability' as a facet in the analysis of rural poverty. Here, vulnerability was taken as one of the four elements which included,

[16] It is important to note that there is a large body of vulnerability literature that is not addressed here. This relates to literature on vulnerability in the context of the countries of the Global North. In these countries, vulnerability is often studied from a perspective of the condition of late modernity, focussing more on technological hazards and solutions particularly meant for more affluent societies with strong institutions. Authors such as Beck (1992) highlight that in these countries, risks and vulnerabilities are far removed from major sections of society due to their not directly encountering these risks in a sensory manner. Wisner et al. (2003) mentions that this literature lies in stark contrast to the socio-cultural and institutional environment of risk prevalent in most societies of the Global South where risks are felt immediately by a majority of the people and environments in question.

political powerlessness, ill health, isolation and income poverty. Interlocked with each other, these elements created a trap from which it was difficult to emerge. **Sustainable livelihoods** were at the centre of this stream of research, where a sustainable livelihood refers to a set of capabilities, assets and activities that lead to the well-being of a person or household (Chambers & Conway, 1992; Ellis, 2000). Vulnerability is the susceptibility to the incapability to sustain a livelihood. The livelihood approach as it was termed, broadened the constraints on 'entitlements'; it focused on the ability of people to sustain their livelihoods, especially when stressed (Eakin, 2005; Scoones, 1998).

As Adger (2006) indicates, the above concepts were most often applied in the context of development assistance and poverty alleviation and therefore largely side-stepped the physical and ecological dimensions of risk. They have however provided the foundation upon which all vulnerability research is now based.

Second Dimension: Political Economy/Political Ecology

Blaikie and Brookfield (1987) built on the work conducted previously and introduced the idea of 'vulnerability' as an important facet of rural poverty, but also as an element of hazard. The physical risk factors were often assessed as a separate science and as factors that were external and therefore not easily merged with the social sciences. The authors used vulnerability as a mechanism to determine the degree to which one's social status influences differential impact by natural hazards and social processes. Social status refers to culturally and socially constructed roles, responsibilities, rights, duties and expectations concerning behaviour (Wisner et al., 2012).

A significant development was the introduction of the **'Pressure and Release'** (PAR) model of hazards by Blaikie et al., (1994). The framework was one of the first to incorporate the physical and social dimensions of vulnerability. They prescribe actions for recovery, and mitigation of disasters that focused explicitly on reducing vulnerability (Adger, 2006). In this context vulnerability is defined within three progressive levels: root causes, dynamic pressures, and unsafe conditions (Wisner et al., 2003). In this literature, vulnerability is not considered an outcome but rather a dynamic state or condition of being, moderated by existing inequities in resource distribution and access, the control individuals can exert over choices and opportunities, and historical patterns of social domination and marginalisation (Eakin & Luers, 2006). This research is an amalgamation of the first dimension (where research was largely focused on poverty alleviation and livelihood security) and the introduction of a second dimension (from a physical/ecological standpoint).

The political ecology approach, in particular the PAR model, has been applied in varying studies examining the causes and consequences of hazards (Gaillard et al., 2009; Mustafa, 2008;

Singh et al., 2014; Singh, 2014). These authors find that understanding the root causes and determining the level of preparedness of populations, helps in implementation of targeted and more effective adaptation measures, so as to prevent further decline. These results resonate with an important piece of work on disaster risk by Lewis (1999) who identifies that in addition to their biophysical drivers, natural disasters are determined by the vulnerability of populations and settlements (due to the collective impacts on their basic services and human well-being).

While both social and natural systems are included in the framework, Cutter et al. (2009) critique this approach for not adequately addressing the interactions between the social and natural systems in producing the said hazard in the first place. Furthermore, the heavy emphasis on pressure from national and global levels does not allow for the inclusion of the pressures that can arise from local conditions (Cutter & Emrich, 2006).

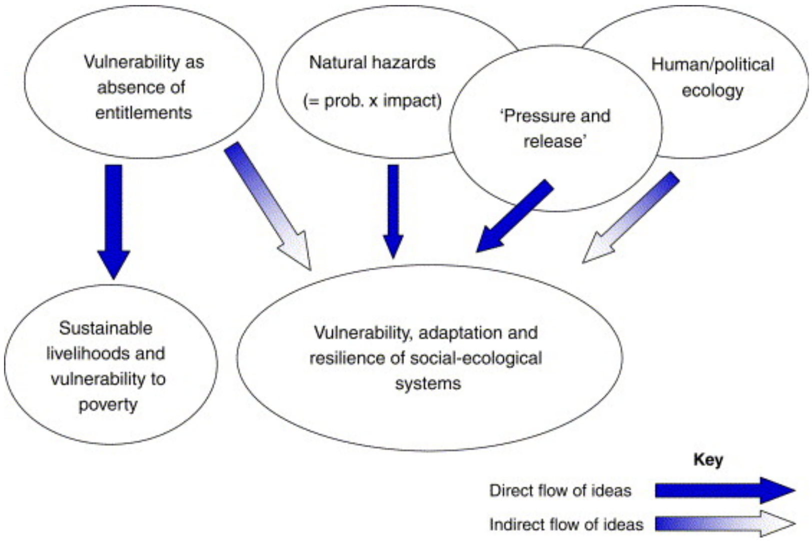
Third Dimension: Hazards and Risk

By contrast, the **natural hazards approach** or hazards of place approach is largely directed at environmental risk factors. This includes research by Brooks (2003), Burton et al. (1993), Cutter (1996) that approaches vulnerability as a result of the type and probability of natural stressors, thresholds of risk, the potential of exposed people to experience damage and possible adjustments. It was introduced by Cutter (1996) and describes the place-based interaction between biophysical vulnerability (exposure) and social vulnerability in an overall determination of the differential social burdens of hazards and how this relationship changes over time and across space (Cutter et al., 2009).

One of the prominent adoptions of the hazards of place approach has been that of O'Brien et al. (2004b). Using the example of Indian agriculture, the authors use exposure and adaptive capacities of districts in India to climate change and other global stressors. Other studies using the hazards approach incorporate multiple hazards or multiple stressors along with demographic information at specific spatial scales such as metropolitan areas (Chakraborty et al., 2005; Collins et al., 2009) or county (Azar & Rain, 2007; Boruff et al., 2005).

The approach introduced the idea of biophysical impacts as a critical facet of vulnerability conceptualisations. It is also considered one of the more applicable frameworks for empirical testing (Adger, 2006). More recent adoptions of the approach (e.g. Schmidtlein et al., 2008; Wisner et al., 2012) have also improved upon incorporating measurements of social vulnerability to natural hazards in addition to the biophysical impacts (Figure 2.2).

Figure 2.2: Traditions in vulnerability research and their evolution



Source: Adger (2006)

Fourth Dimension: IPCC and Climate Change

Most recently, the assessment of vulnerability has received an impetus in the context of global climatic change. Studying vulnerability in this literature has helped illuminate why not all natural hazards lead to natural disasters. It is now widely understood that many natural hazards (such as a climatic event) become disasters when they hit a large section of society that is vulnerable (Wisner et al., 2012)[17].

Within climate change research, some of the concepts related to climate change risk, impacts and vulnerability are as follows:

- **Sensitivity:** Refers to the degree to which a system can be modified or affected by a stress or perturbation (IPCC, 2014; Geest et al., 2004; Sietz, 2011). It is a function of the susceptibility of a system to change. The questions asked in an analysis of sensitivity are typically: to what extent is the function and structure of the system likely to be modified by a particular stressor, what are the human-environment conditions that determine this susceptibility, and to what extent will this compromise the capacity of the system to support livelihoods? (Sharma, 2015)
- **Adaptive capacity:** Describes the ability of a system to adjust to actual or expected perturbations, take advantage of opportunities, or respond to the consequences (IPCC, 2014). It is typically considered a function of existing wealth, technology, education, information, skills infrastructure, access to resources, and management capabilities (ibid.)

[17] If the event is large enough (e.g. a Tsunami) all people are likely to be become vulnerable.

- **Exposure:** Relates to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2014: 123). Recent research views exposure as an exogenous factor to be dealt with separately from vulnerability (IPCC, 2014; Joakim et al., 2015; Sietz, 2014). This will be discussed in detail.
- **Hazard:** Refers to the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision and environmental resources (IPCC, 2014).
- **Resilience:** While vulnerability provides an understanding of the social, economic, historical, cultural and political processes that lead to increased risk, resilience provides the opportunities for moving forward and reducing the impacts of shocks and stresses associated with climate change (Joakim, 2013). Resilience refers to the magnitude of disturbance that can be absorbed before a system changes to a radically different state (IPCC, 2014; Adger, 2006). It is the capacity of a system to self-regulate and bounce back to a normal state after any perturbation[18]. Vulnerability research and resilience research have common elements of interest – the shocks and stresses experienced by the social-ecological system, the response of the system, and the capacity for adaptive action. Authors such as Handmer (2003) argue that the term resilience is a more positive concept than vulnerability - which he finds to be unnecessarily negative. Jordan (2015) however finds that framing rooted problems as resilience instead of vulnerability can lead to misunderstandings. Using examples from case studies in Bangladesh the author finds that focusing on resilience can lead to overlooking issues, such as power inequalities present within rural communities. Thus, communities and infrastructure in need of assistance run the risk of being presented as resilient due to their capacity for short-term coping. In this thesis, adaptation is used as a comprehensive term. Increasing resilience and decreasing vulnerability are considered to be universal goals and elemental functions which lie at the heart of adaptation planning (Weichselgartner & Kelman, 2014; Joakim et al., 2015).
- **Maladaptation:** Maladaptation or dysfunctional adaption are concepts that show adaptive capacities can go wrong (Mortimore, 2016). Maladaptation is a cause of

[18] Resilience and adaptive capacity are often used together and scholars such as Folke et al. (2003) view resilience as a precondition for adaptive capacity whilst others like Walker et al. (2002) consider adaptive capacity as an integral component of a system's ability to create and maintain resilience. Folke (2006) highlights that adaptive capacity is the capacity for renewal, reorganisations and development, while resilience is a capacity for absorbing shocks while still maintaining function.

increasing concern in adaptation research, where intervention in one location or sector can increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change (IPCC, 2014; Klein et al., 2007). There is relatively little knowledge on the foundations of maladaptation in theory and it remains a concept that is used in a more practical manner. Research in IPCC (2014) also acknowledges the need for further research into maladaptation in order to determine if it arises out of badly planned adaptations or deliberate decisions where wider considerations place greater emphasis on short-term outcomes as opposed to longer term impacts.

The above concepts are now regularly used in conceptualisations of vulnerability. They have essentially emerged from vulnerability literature since the 1980s. Vulnerability research in the context of climate change has, in some ways, a unique distinction of being a widely accepted and used term and an integral part of a scientific agenda. This is probably fitting as climate change itself represents a classic multi-scale global change problem in that infinitely diverse actors, multiple stressors and time scales are involved (Adger, 2006). Climate science has adopted the concept of vulnerability as an amalgamation of the socio-economic, political, cultural, and ecological factors that are a crucial link between climate impacts and their outcomes. Debates however ensue on how the many factors interact with each other.

The evolution of vulnerability thinking within climate change literature also offers valuable insights. It is evident through a shift in the scientific framings of the relationship between vulnerability and its constituent elements within the IPCC's Assessment Reports (AR) over the years. These are discussed below:

1. AR3 (2001) and AR4 (2007) define vulnerability as an **outcome**: This is also referred to in literature as an 'end-point' or 'top-down' approach to vulnerability (Dessai & Hulme, 2004; O'Brien et al., 2004a). It is considered a linear result of the projected impacts of climate change on a particular exposure unit (which can be either biophysical or social), potentially offset by adaptation measures. Vulnerability here is the overall impact of a disturbance on a system (O'Brien et al., 2007).
2. AR5 (2014) defines vulnerability as **contextual** or the pre-existing state of a system: This is defined as the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. This is also referred to as 'starting-point' (Kelly & Adger, 2000) or 'endogenous' (Sietz, 2011) vulnerability. Here vulnerability is the amalgamation of the existing political, institutional, economic and social structures that are inherent to a system, irrespective of the impact on it.

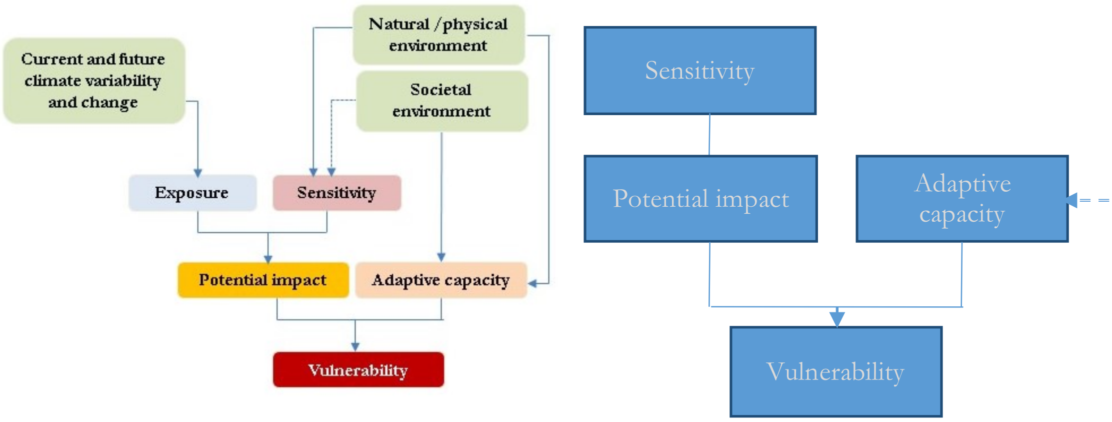
Vulnerability is part of a broader framework of risk that incorporates concepts of exposure and hazard.

Since AR3 and AR4, research in the field showed that the scientific framing of vulnerability as an 'outcome' tends to generate solutions that are impacts-driven; ignoring the fundamental causes of vulnerability (Jones et al., 2010; O'Brien et al., 2007; Sietz, 2011; Wisner et al., 2012). For instance, adaptation policies are often geared towards local capacity building and technological changes in the immediate aftermath of a particular climatic event, without considering the socio-political landscape within which interventions are designed, leading to ineffectual strategies (O'Brien et al., 2007). Ribot (2009) emphasises that the relationship between climate impacts and its outcomes (whether it is a one-time large-scale disaster or a slower impact change such as land degradation) is complex and non-linear and climate events or trends are transformed into differentiated outcomes via social structure. These social structures are driven by the existing and potential vulnerabilities faced by communities, institutions and their inter-relations. Thus, in order to present frameworks that better support local decision making in the context of climate change, AR5 shifted its focus to the concept of 'risk', arising from the interactions between vulnerability, exposure, and hazard. Figure 2.3 and 2.4 illustrate the differences between the two conceptualisations of vulnerability under the IPCC.

IPCC's AR5 (2014) indicates that the differences in vulnerability arise due to endogenous factors such as the multi-dimensional inequalities produced by uneven development processes. These endogenous factors then shape differential risks posed by the exogenous factors (e.g. climate). Therefore, people who are socially, economically, culturally, politically, institutionally or otherwise marginalised are especially vulnerable to climate change and also to some adaptation and mitigation responses (Costa et al., 2011; Eakin & Luers, 2006).

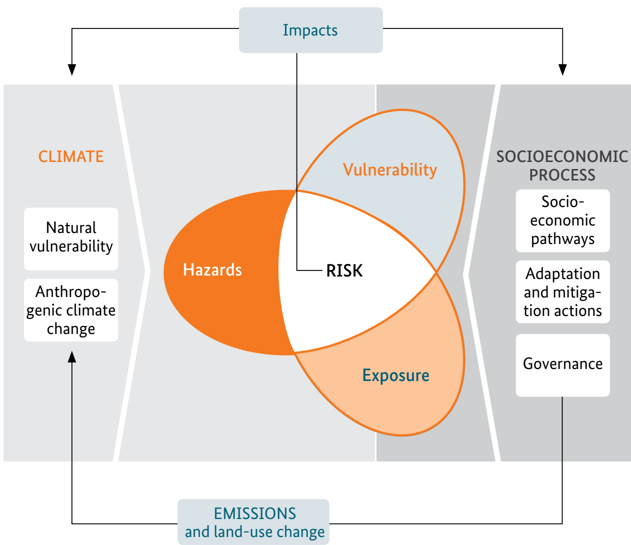
Figure 2.3: Components of vulnerability according to IPCC AR4 (2007) and AR5 (2014). AR4's definition of vulnerability – "it is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity, and adaptive capacity of that system". AR5 defines vulnerability as – "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt".

IPCC – 2007 'Outcome vulnerability' **IPCC 2014 – 'Endogenous vulnerability'**



Source: Adelphi/EURAC 2014; IPCC 2014

Figure 2.4: Risk assessment framework of the IPCCs AR5 where 'exposure' and 'hazards' are considered separate to the vulnerability of a system. Vulnerability resides within a system as a system property determined by its sensitivity and lack of adaptive capacity. The interaction of 'vulnerability', 'exposure' and 'hazard' together constitute 'risk'. Changes in the climate and broader socio-economic processes drive risk.



Source: IPCC (2014)

This definition and concept echoes some key elements of the earlier frameworks mentioned. For instance, the research of Lewis (development and disaster), Wisner (pressure and release framework), and Chambers and Conway (sustainable livelihoods approach) all put forth vulnerability as a pre-existing state of a system. Rather than as a direct 'outcome' of a perturbation or stress, a combination of processes such as, assets, institutions, and socio-ecological dynamics are now shown to interact with vulnerability and characterise it.

There is also another less common stream of climate change research that views **vulnerability as a threshold** (see Joakim et al., 2015). A threshold is defined as 'a level or point at which something starts or ceases to happen or come into effect' (Soanes & Stevenson, 2008: 1502). It relates closely to AR4's 'outcome' approach, but involves the simulation of thresholds (e.g. mortality thresholds to heat stress) or identifying levels after which citizens are not able to cope with or adapt to climate change impacts (Adger et al., 2009; Jurgilevich et al., 2017). It assumes that social–ecological systems can absorb significant perturbations if they are resilient. However, when thresholds are breached, they often undergo significant regime shifts into alternate states that may indeed be resilient, yet are often undesirable from human perspectives. Joakim et al. (2015) demonstrate that identification of these thresholds using community perspectives can serve to understand when damage occurs, and how adaptation can help. However, as Jurgilevich et al. (2017) state, this can be challenging since it would first require identification of acceptable levels of damage until it becomes 'unbearable' (from stakeholders themselves), and secondly, would need complex simulations, dynamic trend assumptions and socio-economic scenario building which are yet to be fully developed and tested within vulnerability research. Additionally, while some thresholds can be quantified, Meze-Hausken (2008) argue that others can only be defined through subjective assessments of levels of acceptable risk and impact, derived through experience and expectation. This concept is later drawn upon in Chapter Six, where a subjective assessment of thresholds is conducted using community perspectives of shifts in the quality of their land, water and biomass resources.

In summary, vulnerability conceptualisations differ based on approach, quality, and quantity of its many components. The IPCC's concept of vulnerability (sensitivity and adaptive capacity) has been the most appropriated and used in recent times due to its focus on addressing the inherent complexities of socio-ecological systems alongside the challenges presented by global environmental change (Sietz et al., 2011). The IPCC through its analysis of more than 20,000 papers and reports on climate change synthesises the essence of the diverse perspectives that have been integrated into conceptualisations of vulnerability through different disciplines.

The next section addresses how vulnerability once conceptualised can be assessed. Vulnerability assessments seek to operationalise the concepts of vulnerability discussed thus far, so as to make them useful for research and practice. They can cover a range of methodological bases (qualitative, quantitative, mixed methods) and incorporate a range of epistemologies (outcome or endogenous).

2.5 Assessing vulnerability: Concepts and challenges

Vulnerability assessment describes a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings (Hahn et al., 2009). Vulnerability assessments help in raising awareness, allocation of adaptation funds, targeting of regions or communities for interventions, and monitoring of adaptation policy through identifying vulnerable people, regions or sectors (Hinkel, 2011). It is useful to understand the causes of vulnerability and is most useful as a tool for decision makers to prioritise or target resources in designing vulnerability-reducing interventions and adaptation plans (Hesse, 2016; Smit & Wandel, 2006). Planning for adaptation is therefore one of the main utilities of a vulnerability assessment. For instance, the World Food Programme (WFP) often uses vulnerability assessments to target food aid to the right households in the aftermath of a famine. In flood-prone areas or areas with coastal risks, vulnerability assessments are used to identify communities or households most vulnerable to the impacts of floods or sea-level rise, so as to target anticipatory adaptation plans (Huq et al., 2004; Nguyen et al., 2015). Reducing vulnerability to current risks is often viewed as a first step towards adaptation to future climate change (IPCC, 2014).

As evidenced thus far, vulnerability literature is covered under several research streams across several environmental and socio-economic disciplines (Giupponi & Biscaro, 2015). Therefore, assessment methodologies tend to also be varied and widely debated.

2.5.1 Current approaches to vulnerability assessment

Empirical research identifies several methods to capture and measure vulnerability, each with their advantages and disadvantages. Qualitative methods are used to identify key vulnerability drivers, understand adaptation strategies, and deconstruct local parameters, such as gender and institutions (Birkmann, 2006). Quantitative methods are used to develop proxy indicators, used to compare the vulnerability of places and trends over time (Tate, 2012). Mixed methods are less common in vulnerability research but tend to be applied by NGOs (e.g. Action Aid) or developmental organisations in local level assessments (Faulkner & Iqbal, 2012).

Quantitative vulnerability assessments, using criteria and indicators that are aggregated to form a vulnerability index, are the most widely used method of assessing vulnerability (Beccari, 2016; Tonmoy et al., 2014). The development of an index whether at national, regional, or local scales, involves aggregating multidimensional variables or indicators. The index results in a numerical value that can provide valuable information about the key drivers of vulnerability. This in turn may incorporate a system's sensitivity and lack of adaptive capacity. For example, Hahn et al. (2009) incorporate criteria and indicators to form household livelihood vulnerability profiles in Mozambique. Key criteria (and examples of indicators in parentheses) used in their study include: socio-demographic profile (e.g. percent of female headed-households), livelihood profile (e.g. percent of households' dependent on agriculture), health (e.g. percent of households with a family member with chronic illness), food (e.g. percent of households' dependent on farm for food) and social networks (e.g. average lend to borrow ratio of a household) (ibid.).

While authors such as Hahn et al. (2009), Shah et al. (2013), Gerlitz et al. (2016) use largely socio-economic criteria, most vulnerability assessments tend to rely on biophysical indicators of assessment. McDowell et al., (2016) in a review paper find that even where social dimensions are incorporated as indicators, tokenism is prevalent in a relatively large proportion of studies vis-à-vis the socio-economic/political dimensions of vulnerability. For instance, while gender is often incorporated as a component, there is very little understanding of the cultural context of gender relations and how indicators can be translated into useable frameworks, such that vulnerability of women in a specific location can be addressed (Bunce & Ford, 2015). This is largely due to the nature of criteria and indicators selected for assessments. They tend to be easily quantifiable indicators with accessible datasets, which for the socio-economic parameters are usually limited to demographic or income indicators.

Bridging the gap between social, natural, and physical sciences is now a central goal in vulnerability assessments. For instance, the Sustainable Livelihoods Approach (Chambers & Conway, 1992) is sometimes used to categorise indicators and incorporates five types of household assets—natural, social, financial, physical, and human capital[19]. Studies including Knutsson & Ostwald (2006) use the approach to categorise vulnerability indicators, such as groundwater (natural), expenditure on social events (social), income (financial), house and vehicle (physical), and number of children (human).

However, as Scoones (2009) highlights, many authors have found that the Sustainable Livelihoods Approach may not sufficiently capture multi-scalar dynamics and interlinkages between politics, power relationships and governance. These interlinkages are essential to adequately understand vulnerability. Vulnerability is place-based, context-specific and is practically a relative measure (Claessens et al., 2012, Cutter et al., 2009, Hinkel, 2011, O'Brien

[19] For example, the Sustainable Livelihoods Approach is a commonly used approach to design development programming at the community level.

et al., 2007). Thus, several factors/mechanisms interact to determine it. Researchers thus face several challenges in incorporating these interactions into vulnerability assessments.

2.5.2 Challenges in assessments of vulnerability

Despite criticisms, quantitative assessments using indicators remain the most widely used method in assessments of vulnerability. The vulnerability index is a particularly powerful empirical tool used in most development planning to compare and rank two or more systems e.g. two or more regions or community groups (Sharma et al., 2013; Tate, 2012). Despite the consistent use of quantitative vulnerability assessments, authors are typically either strongly for or against quantification of vulnerability. Alwang et al. (2001) highlight that attempts to reduce vulnerability to a single metric can hide its complexity. Vulnerability when quantified thus needs to adequately reflect complexity. Importantly, there are no other widely used systematic means to assess vulnerability. For instance, there are no established qualitative frameworks for assessing vulnerability.

Some of the common challenges faced by current assessments of vulnerability are discussed:

- **Choice of scale:** Vulnerability is scale dependent and may be much larger locally in pockets than assessed at a higher level (Malone & Engle, 2011). When conceptualised at regional or higher levels, varying distribution in smaller pockets is missed. Most assessments are conducted with a larger-scale focus and lead to consequent loss of vulnerability profiles at a local level (Sietz, 2014). Local level assessments are often perceived as contextual and having no use beyond the scope of the area of study. However, as more researchers conduct assessments at this scale, aggregations can be more viable. A number of vulnerability assessments at a community level can lead to greater understanding of impacts in the region as a whole. For instance, Kok et al. (2016), Sietz et al. (2017) develop vulnerability profiles at a regional and global level using patterns of vulnerability derived from studies of smallholder farmers.
- **Temporal dynamics:** There also remains a need to develop a more sophisticated understanding of temporal change in vulnerability. Uncertainty due to the dynamic nature of vulnerability is inadequately understood because of the difficulty of capturing changes over temporal scales (Dilling et al., 2015). The distinction between current climate variability and future climate change is often blurred within the context of vulnerability assessments.
- **Emphasis on sustainability:** The ecosystem services framework suggests that livelihoods are ultimately dependent on the primary services derived from stocks of

natural capital. This entails that a sustainable livelihood[20] must maintain critical stocks of natural capital (Ekins, 2003; Reed et al., 2013). When assessing the viability of current capacities to adapt, vulnerability research rarely engages with debates on whether current capacities threaten the long-term ability to maintain critical levels of natural capital (Reed et al., 2013). Thus, the question of whether current capacities to adapt are sustainable needs to be asked (e.g. groundwater levels could decline with use).

- **Limited usability:** Authors including Ford et al. (2013) demonstrate that while most vulnerability research explicitly indicate the desire to inform decision-making according to principles of useable science[21]; few are able to actually do so. Vulnerability assessments are typically conducted using larger scale secondary data, which at a field level can limit its utility for adaptation. Further, there remains limited integration of the biophysical and socio-economic drivers of vulnerability. McDowell et al. (2016) find that limited involvement of local stakeholders in co-developing indicators is a likely reason for persistent gaps between the issues being evaluated by researchers and those of interest to decision makers.

In order to overcome these challenges, clarity is needed when devising a vulnerability assessment. At the outset, it is important to mention the choice of scale, whether indicators assess present or dynamic vulnerability, and to incorporate stakeholders at multiple stages of assessment to ensure the assessment has practical value.

2.6 Vulnerability assessments in dryland agro-ecosystems

Assessments of vulnerability tend to be more populated in regions and sectors that are highly climate sensitive including sectors and regions susceptible to extreme events, sea-level rise, and coastal erosion (Mcdowell et al., 2016). This is reasonable, since these regions are under constant threat of disaster risk and are home to vulnerable communities that are the least responsible for the current global circumstances (e.g. coastal zones) (Füssel, 2010). Vulnerability in drylands, with their inherently variable climate and high-risk communities and landscapes (Geest et al., 2004), is yet to be adequately addressed in research.

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[20] Sustainable livelihoods - A livelihood comprises the capabilities, assets (including both material and social resources) and activities for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base (Chambers and Conway, 1992).

[21] Both studies characterise useable science through the following principles (i) research investigates factors under the influence of decision makers (pertinence); (ii) research is trusted and valued by decision makers, and therefore likelihood of begin acted upon (quality); and (iii) the extent to which information is available in time for decision makers (timeliness).

This chapter has shown that drylands are now considered as coupled social-ecological systems in which human activities and environmental dynamics are deeply entwined (Whitfield et al., 2011). As socio-ecological systems, they are inherently highly vulnerable and are likely to become more vulnerable in the future (Huang et al., 2017). Ascertaining the causes and consequences of dryland vulnerability has only recently been highlighted as an area for future research and development. Fraser et al. (2011) emphasise the urgent need to develop methods to anticipate vulnerability, focus on resilience, and envision adaptive strategies.

More recently, a few vulnerability assessments, specific to dryland agro-ecosystems, have been carried out. Dougill et al. (2010) apply a conceptual framework of vulnerability in the Kalahari region of Botswana. In relating their work closely to the climate change vulnerability literature, the authors characterise vulnerability as a result of relatively small climatic changes that have commensurately large and negative impacts on livelihoods. The authors conduct dynamic systems modelling using existing farmer narratives (from previous literature in the region). They find that increasing access to markets and improving empowerment of poorer farmers through community-based management committees and formal syndicates can reduce vulnerability. However, as the authors themselves recognise, the model includes high uncertainties and is based entirely on the judgement of experts and preliminary economic appraisals. They emphasise the need for more participatory involvement in focussing findings and future appraisals that use their approach (ibid.).

The value of using field-based evidence to study vulnerability has also been emphasised by Sietz et al. (2011), Sallu et al. (2010) and Young et al. (2010). For instance, Sallu et al. (2010) conduct a primarily qualitative analysis in rural Botswana. The authors use a livelihood trajectory approach to explore the shocks and stresses that affect livelihoods and contribute to increased resilience or vulnerability of livelihood strategies. The authors highlight the importance of 'everyday details' in each narrative, which can have a profound influence in unpacking household livelihood trajectories and resilience.

A majority of other research comprises broader-scale assessments; authors such as Ferrara et al. (2012) and Salvati et al. (2008) use global or regional indicators to identify and compare vulnerabilities of different groups to desertification. Salvati and Zitti (2009) proposed an index of land vulnerability to drought and desertification, using both ecological and economic variables. The authors find that incorporating relevant socio-economic parameters into such indices still remains difficult due to two reasons (i) the qualitative nature of many of the social indicators of importance and (ii) the infrequency with which social indicators and statistics are updated at broader regional and global levels (Imbrenda et al., 2013; Salvati & Zitti, 2009b).

From the above it is clear that there are currently few vulnerability assessments conducted specifically for dryland agro-ecosystems. There are even fewer assessments conducted in the arid drylands of the world, due to perceptions that they have low biological potential, low productivity potential and low population densities (Reynolds & Stafford Smith, 2002; Schimel, 2010). Furthermore, authors such as Reed and Stringer (2016) and Hultman et al. (2010) acknowledge that incorporating the complex socio-ecological system characteristics of drylands, within current framings of largely quantitatively analysed vulnerability, can be challenging. Some dryland researchers suggest that quantifying the risks presented by climate change to drylands may be "beyond the capabilities of objective scientific enquiry" (Whitfield & Reed 2012: 2), due to the value judgements involved. The authors however acknowledge that this can be overcome if scientists find ways to incorporate value judgements from the point of view of local stakeholders as an essential component of assessment methodologies (ibid.). Furthermore, research by Kok et al. (2016), Sietz (2014), Fraser et al., (2011), Hahn et al. (2009), Chuluun et al. (2014) has shown that quantifying vulnerability can in fact add significant value to existing research in drylands.

These debates are important for this research as they reveal that there remains a need to demonstrate the viability of differing epistemologies and methodologies with respect to differing drylands. It is imperative that new and interdisciplinary research agendas, that use both qualitative and quantitative methods are developed focusing on agriculture and livelihood security in these risk-prone environments. As authors such as Whitefield and Reed (2012), Cutter (2009), Miller et al. (2010) and Preston (2012) state, provided assessments are suited to the application to which they were devised, vulnerability can provide many answers that can help unravel complex socio-ecological system dynamics. Adger (2006) in acknowledging the diversity of epistemologies and methods in vulnerability research considers it an advantage rather than a problem.

Vulnerability continues to remain a concept that offers remarkable promise in understanding many rooted problems as evidenced in research (Burton et al., 2002; Eriksen & O'Brien, 2007; Füssel, 2010; Räsänen et al., 2016; Robinson et al., 2015; Turner, Kasperson, et al., 2003a). In the context of this study, the use of vulnerability adds value due to the following: (i) its inter-disciplinarily value (it continues to be researched and used across many disciplines); (ii) it offers the ability to acknowledge problems presented by the current global climate challenge; and (iii) it allows for inclusion of socio-ecological systems interactions that are central to understanding dryland agro-ecosystems.

The next section draws attention to the overall research gaps identified thus far, bringing together discussions of dryland degradation and vulnerability, focusing attention on particular areas of work that this thesis aims to explore.

2.7 Highlighting the scientific knowledge gaps

A review of literature conducted in this chapter has indicated that there is a lack of clarity on the concept of dryland degradation, its definition, and processes. The concept of desertification - where local farmers and pastoralists continue to be cited as primary agents of irreversible degradation - has become institutionalised. This is despite the presence of scientific evidence that demonstrates that the processes leading to degradation are much more complex and dynamic, involving multiple interactions and feedback effects. To this end, Behnke and Mortimore (2016: 11) state that the concept of desertification is unlikely to be analytically useful and "we should instead struggle to better define and operationalise the admittedly difficult concept of dryland degradation".

Research in drylands has also been at the centre of a constant tussle between top-down and bottom-up approaches (Toulmin & Brock, 2016). While global assessments attempt to identify and maintain uniformly good dryland environments (e.g. certain levels of vegetation, crop productivity), field research questions the attempt to maintain such homogenous environments (Behnke & Mortimore, 2016; Rutherford & Powrie, 2010). Field research in drylands has instead demonstrated that it is this heterogeneity of drylands that is responsible for sustaining diverse plants, animal species and environmental services, despite climate uncertainty and neglect by policy (ibid.).

Many dryland researchers have thus supported the call for more field-driven studies at multiple-scales. Van Walsum et al. (2014: 68) highlighted their belief in the need for participatory research processes with local farmers as a means to bridge the gap between local experience and scientific evidence.

> "The success of land management can only come about if scientists listen well and open their minds towards a new way of understanding local farmers by working towards a multi-functional approach to agriculture. If scientists succeed in this, they are ready for a refreshing scientific experience that may well lead to many valuable new perspectives and insights".

As shown in section 2.3, it is now widely acknowledged that both biophysical and socio-economic driving forces need to be considered alongside local knowledge in designing strategies that aim to achieve land degradation neutrality. Despite widespread affirmation of these principles and the presence of newer participatory management frameworks, there are no established frameworks in place for assessing multidimensional variables in drylands. The main challenge lies in unravelling the varying levels of interactions between complex phenomena that occur on multiple temporal and spatial scales (Mortimore, 2009; Turnbull et al., 2012). The two major constructs missing in dryland research today are articulated by Verstraete et al. (2009: 427):

> "(i) The need to structure and present what has been learned so far in dryland research in a much more accessible manner, so as to be useful; (ii) To pursue open-ended investigations that explore processes and variables thought to be important, critically scrutinising past and current hypotheses, and being especially mindful of possible unintended consequences of actions and decisions that contribute to the problem rather than the solution".

Importantly, drylands due to their marginalised populations, heavy dependence on land resources, and variable rainfall patterns are inherently vulnerable, yet resilient. Prominent assessments of vulnerability in drylands have been highlighted in this chapter. As seen earlier, a majority of this research and existing policy initiatives generally aim to understand the relevance of dryland vulnerability to the impacts of global climate change. While these outcomes are tremendously important in light of global problems, at a local level, there remains a need to first diagnose and understand the inherent system dynamics, its strengths and constraints. This is largely because research is often forced into two separate strands: One branch of research looks at the drivers or causes behind land degradation, while another focus on the consequences, in terms of vulnerability and adaptation to climate variability and change. As this chapter has shown, the reality in drylands is much more multifaceted, and drivers and consequences of dryland degradation are not always distinct. Thus, without the bridge of climate change, research frameworks on 'dryland degradation' and 'vulnerability' have for the most part been separate. Barring a few studies (e.g. Geest & Dietz, 2004; Kattumuri et al., 2017; Sallu et al., 2010), there is a common misunderstanding of the relationship between the two phenomena: poor people live in drylands (and put pressure on the land) and therefore drylands are vulnerable to any impacts of climate change.

Reed and Stringer (2016: 173) echo this in their diagnosis of constraints for drylands. The authors state that one of the remaining research gaps is:

> "How do we best characterise and understand the vulnerability and adaptive capacities of ecosystems (in particular agro-ecosystems) and human populations in affected regions (areas facing degradation and desertification), including regions newly susceptible to the consequences of climate change?"

The UNCCD's (2013) White Paper I on the impacts of dryland degradation clearly identifies the need for developing a dryland-specific vulnerability index:

> "An index of the more all-encompassing interdisciplinary concept of the vulnerability of communities living in a given (dryland) environment is still awaited" (Low, 2013).

This thesis aims to bridge some of these critical gaps in drylands research by using vulnerability as an overarching framework within which to explore socio-ecological system linkages that surround land degradation in dryland agro-ecosystems. As Lewis (1999: 4) states in his research of disaster risk, "The vulnerable state of populations and settlements is as much a contributor to the cause of 'natural' disasters as are the physical phenomena with which they are associated".

2.8 Conclusions

Overall, there remains a need to uncover the underlying dynamics and characteristic responses to environmental drivers and human-induced disturbances whilst keeping in mind the vulnerability of dryland agro-ecosystems. This review of the relevant research has highlighted that literature on dryland degradation and vulnerability tend to be addressed separately. A review of studies thus far showed that several challenges hinder field-based as well as conceptual studies when assessing the vulnerability of dryland agro-ecosystems. It is necessary to resolve these challenges. Despite criticisms, there is now greater knowledge of the complexity and dynamic nature of sustaining human-environment systems in an environment faced with an equal amount of complexity and dynamic ability as exists in drylands. Research from specific disciplines such as soil science, hydrology, biodiversity, climate science, sociology, anthropology have drawn together inferences that are of great value to understanding the causes and consequences of dryland degradation. Using methods and information gathered from these sources, analysing and amalgamating some or all the attributes that together make up the vulnerability of dryland agro-ecosystems should therefore be feasible.

Having discussed the varying threads of literature key to this thesis, the following chapter aims to situate these debates within the specific context of the arid zones of north-west India. In Chapter One, the decision to ground the empirical research of this thesis in India, and more specifically in Rajasthan, has been identified. While literature and field-driven studies in the drylands of Africa and Latin America have been discussed in this chapter; a critical knowledge gap identified here is the lack of similar research in the drylands of South Asia in general and India in particular. There is a need for research to better clarify how debates central to global drylands translate to India's drylands. It is important to recognise the unique knowledge and wisdom present within India's dryland communities, and their relevance to better understanding dryland degradation globally.

3. Rajasthan – An Exploration of the Region of Study

The previous chapter explored the significant strides taken in drylands research to understand the factors driving and exacerbating dryland degradation. While advances in climatology and remote sensing technologies have provided clarifications of larger-scale processes, scientists highlight the need to conduct simultaneous field-driven studies that explore the varying interactions between biophysical, socio-economic and climatic factors in drylands. This chapter provides the background to the arid drylands of Rajasthan, India where this study is empirically situated. This helps put in context the analysis and findings presented in the remainder of the thesis.

In India, dryland problems including land degradation and socio-political marginalities are persistent and arid drylands are given scant attention in research and policy. Moreover, the sophisticated debates surrounding processes contributing to dryland degradation globally, are almost entirely lacking in the context of India's drylands. Despite the presence of much research and scientific discussion on the logical and empirical shortcomings of the concept of human-led desertification, the theory is remarkably institutionalised in the arid and semi-arid drylands of India. Research in India continues to present the arid dryland landscapes as non-productive wastelands and dryland communities as the primary drivers of degradation.

Drawing on the research gaps identified in Chapter Two, this chapter aims to situate these debates in the context of the oft-neglected arid drylands of India. In particular, the chapter introduces the district of Jodhpur in the arid western plains of Rajasthan, where the research is positioned. The district of Jodhpur is symptomatic of typical arid zone problems in India; it faces persistent dryland degradation and newer climatic risks. As emphasised in Chapter One, arid Jodhpur is a fascinating region in terms of the rich cultural and political legacy contained within its agrarian landscapes. Degradation of land resources thus brings with it unique and extraordinary challenges in tackling long-term sustainable development goals in the region.

Due to a relative lack of systematic information about the arid regions of Rajasthan, this chapter provides a description of the study area. The information used brings together data from a range of secondary sources including: Government of India (GoI), Government of Rajasthan (GoR), international development agency reports such as UNDP, FAO and World Bank, reports from research organisations such as CAZRI, NICRA, and ICAR; peer-reviewed research articles in addition to observations from original fieldwork. The chapter is structured as follows:

- Section 3.1 introduces India as the region of study, focusing on key features of India's drylands;

- Section 3.2 focusses on Rajasthan, highlighting in particular the state-level institutional context within which land is governed;
- Section 3.3. introduces Jodhpur district, the location of the field research giving a description of the present state of its environment and socio-economic development;
- Section 3.4 traces the evolution of agrarian and social landscapes in Jodhpur's agro-ecosystems - from traditional organisation of society centred on drought to transformations brought on by the Green Revolution;
- Section 3.5 highlights the vulnerability of communities and landscapes in the region to intensifying hazards and the dearth of adequate research in recognising the role of vulnerability; and
- Section 3.6 concludes this chapter, and reinforces the need to understand the local context for this research.

3.1 Region of study: India

With a geographical area of 328 million hectares (Mha), India is the seventh largest country in the world by area. It is the second most populous country in the world, with a population of around 1.2 billion and a population density of 364/sq.km (GoI, 2011). India's geographical location contributes to wide climatic variations, ranging from tropical to arid to alpine, making weather patterns exceedingly unstable. Rapidly developing, India is currently the worlds' third largest economy, with a sustained growth rate of around 7.5% (OECD, 2017). India is however as stratified, diverse, distinct, and juxtaposed as it is large. The country remains steeped in many inequities and is a story of two distinct narratives. The per capital income in India's richer states is four times that in its poorer states. While India's annual per capita income in 2011was USD 1,461; Bihar one of India's poorest states, had a per capita income of USD 294 (World Bank, 2016). More than 400 million people in India, representing one-third of the world's poor, live in poverty[22] and many of the 53 million people who have recently climbed out of poverty (between 2005-2010), are at risk of falling back into it (ibid.). One in three rural people lack access to an all-weather road, and an estimated 300 million people are not connected to the national electrical grid and those who are connected face frequent disruptions (ibid.). Approximately 70% of India's population live in rural areas, and 70% of the rural population depend on agriculture as their principal means of livelihood (GoI, 2011a). Yield data for India's key crops show that productivity is lower than the world average; cereal yield is 2.9 tonnes/ha (t/ha), as compared to the global average of around 4.0 t/ha (World Bank, 2014); in contrast, China produces cereals at 6.1 t/ha (ibid.).

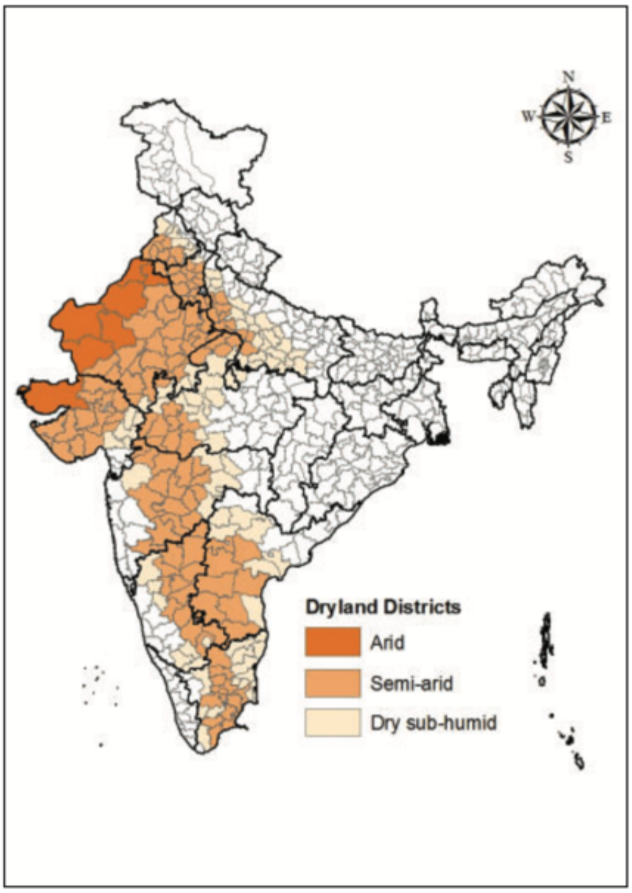
[22] World Bank poverty estimates are based on the $1.90 poverty line and 2011 purchasing power parity prices.

Improving crop productivity and food security through promoting crop diversification and better land management, are therefore top priorities for the Government of India. For planning purposes the country has been delineated into fifteen agro-climatic zones, based on climatic conditions and soil types, which range from the mountains of the Himalayas, forests of the east, western coastal plains, deserts of the north-west and islands of the Indian Ocean (FAO, 2010). The western dry region which is the focus of this study, is one among India's many agro-climatic zones.

3.1.1 Drylands of India: Key features and challenges

Constituting 69% of India's total geographical area (Figure 3.1), India's drylands are classified into arid, semiarid and dry sub-humid. These drylands occupy a continuous stretch in the north-western states of Rajasthan, Gujarat, Punjab, Haryana and scattered landmasses in the southern peninsular states of Maharashtra, Karnataka and Andhra Pradesh (Maji et al., 2010).

Figure 3.1: Location of India's drylands



Source: Raju et al. (2014)

Often the terms, 'drylands' and 'rain-fed regions' are used synonymously in India. Though the descriptions overlap to a large extent, a rain-fed area is a piece of agricultural land where the only source of water is the rain, and no source of surface or groundwater exists (Raju et al., 2014). Conversely, many drylands have irrigation sources from both surface water (such as canals, tanks) and groundwater. The UNCCD (1994) define drylands based on, aridity index (Ia) computed as the ratio of mean annual precipitation to mean annual potential evapotranspiration. Accordingly, in India, areas with arid (Ia = 0.05-0.20), semi-arid (Ia = 0.20-0.50) and dry sub-humid (Ia = 0.50-0.65) climates are termed as drylands (Raju et al., 2014).

Some of the characteristic features of drylands in India are: low and erratic rainfall (annual average precipitation of less than 500 mm); extreme temperatures that can rise to 50°C in the summer (May – June), to below freezing in the winter (December – January); long sunshine durations (between 6 to 10 hours); low relative humidity (around 3%); high wind velocity (9-13 kmph) and high evapotranspiration (1600-1800 mm). Soils are poor in nutrients, wind erosion occurs on a large scale and water scarcity is a perpetual constraint (Kar et al., 2009). Despite these harsh conditions, India's drylands support a wide variety of flora and fauna. They are also home to large human (nearly 40% of India's population) and livestock (60% of India's livestock population) populations, a majority of whom depend entirely on the land for sustenance. Around 80% of dryland farmers are dependent on small and marginal landholdings (Dev, 2012). More than 40% of India's food grains production comes from drylands, but grain yields are low. For instance, 3 ha of dryland produces cereal grains equivalent to that produced in 1 ha of non-dryland (Kumar, 2013). The major challenge in improving agricultural productivity in India's drylands has been land degradation (MoEFCC, 2015a).

3.1.2 Dryland degradation in India

The Government of India defines land degradation in accordance with the UNCCD's definition provided in Chapter Two (Section 2.1). Estimates on the extent of degradation in India exist from the 1960s onwards and vary from 52 Mha to 187 Mha, based on differing source, scale, and methods (Maji et al., 2010; MoEFCC, 2015a; Mythili & Goedecke, 2016). More recently, extensive systematic datasets have been developed using satellite imagery by India's National Remote Sensing Centre (NRSC)[23] (Ajai et al., 2009; Arya et al., 2012).

Two key government sponsored sources produce widely cited estimates of land degradation in India: The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) and the National Remote Sensing Centre (NRSC).

1. NBSS&LUP estimates land degradation using aggregated soil studies. The study defines land degradation in the context of declining productivity due to soil erosion[24].

[23] Previously known as National Remote Sensing Agency (NRSA).
[24] Rainfall erosivity, soil erodibility, topography, vegetative cover, management and conservation practices are the major indicators used to estimate the extent of soil erosion. Soil loss function (t/ha/year), is estimated using the Universal Soil Loss Equation (USLE). It is derived from 1:250000 soil maps

The last India-wide, district-level soil assessment by NBSS&LUP is from 2003 (Shyamapura et al., 2003)[25] and estimated 146.8 Mha of degraded land in India (around 44% of India's total geographic area (TGA).

2. NRSC datasets are spatial, using biophysical information on soil and vegetation, identifying land use and physical conditions by mapping, in addition to some 'ground-truthing' of the physical characteristics through some field visits[26]. NRSC estimates that 96.4 Mha of India's land is degraded (29.3% TGA) as of 2011-13 (Figure 3.2). NRSC's previous land degradation status mapping was conducted in 2003-05 and estimated 94.5 Mha (28.8% of TGA) as degraded land, showing a cumulative increase of around 2% over the six-year period since 2005 (GoI, 2013)[27].

The NSRC remote sensing estimates are lower than the NBSS&LUP estimates. However, it should be noted that these two estimates are not contradictory, as they measure different things (Mythili & Goedecke, 2016), using different methods (independent soil studies vs. remote sensing data analysis). Given the wide agro-climatic diversity of India, ICAR (2010) highlight that incompatible databases and statistics continue to pose significant difficulties for decision makers (Maji et al., 2010). In an effort to harmonise the varying datasets, the ICAR (2010)[28], through a preliminary assessment using both NBSSP&LUP and NRSC information (from 2003-05), estimated total area under degraded land in the country to be 114 Mha (ibid.).

While the NBSS&LUP statistics do not separate dryland degradation or desertification as a separate category, NRSC calculates desertification within their 'Land Degradation and Desertification Atlas of India' (GoI, 2013). The area under 'desertification' is defined in India as per the UNCCD (1993), as land degradation in the arid, semi-arid and dry sub-humid regions of the country (MoEFCC, 2015). In mapping desertification, degraded land area in the whole country (96 Mha) is super-imposed with a map layer of dryland areas, showing that 82.6 Mha of India is undergoing 'desertification' (GoI, 2013). In comparing figures from 2004-05, there is a cumulative increase of 1.16 Mha undergoing 'desertification'. The most significant processes contributing to desertification are wind erosion (in arid regions) and vegetation degradation, water erosion, water logging and salinity (in semi-arid and dry sub-humid regions) (see Figure 3.2).

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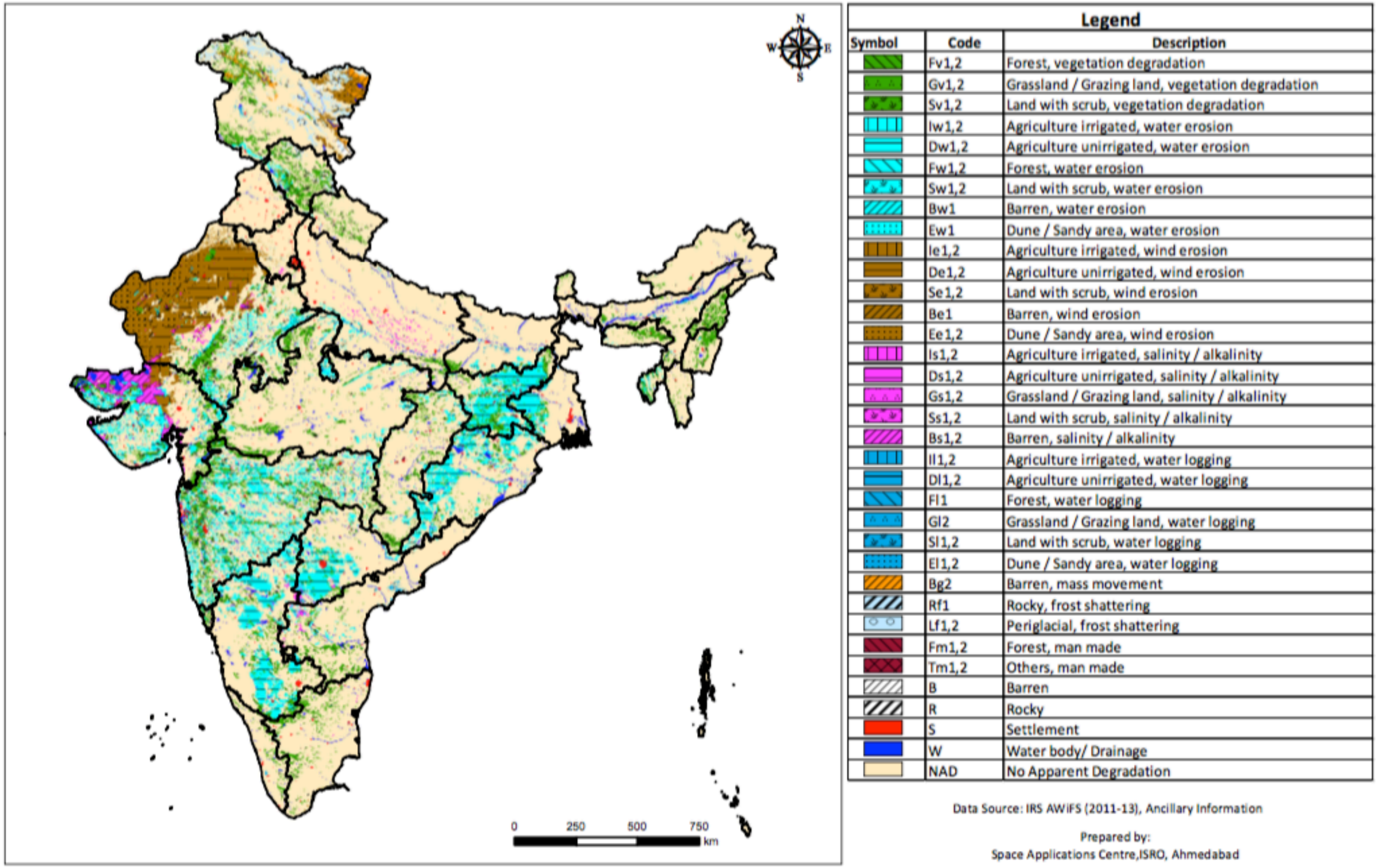
[25] In 1994, NBSS&LUP projected an area of 187 Mha as degraded land following GLASOD methodology (Oldeman, 1988), and revised it to 147 M ha in 2004.

[26] NRSC datasets are represented on 1:50,000 scale

[27] The NRSC also conduct mapping of 'wastelands', as a sub-set of total degraded lands. Wastelands are described as, "degraded lands which can be brought under vegetative cover with reasonable effort, lands which are currently under-utilised and lands which are deteriorating for lack of appropriate water and soil management or on account of natural causes" (NRSC, 2014). Their definition of wastelands does not include degraded areas currently under cultivation. The area under wastelands is reflected within current figures of land degradation.

[28] ICAR's study compares NRSA data from 2000 and NBSS&LUP data from 1995.

Figure 3.2: Desertification/land degradation status map of India (2011-2013)



Source: GoI (2013)

Unlike the rich debates surrounding the concept of desertification globally and in the drylands of Africa (e.g. Toulmin & Brock, 2016), there is a lack of dynamism in debates surrounding desertification in India. As a ratified member of the UNCCD, the Government of India has an obligation to report the extent of land degradation and desertification every four years. 'Desertification' as a term therefore continues to be used uncritically in estimating land degradation of dryland areas. It is monitored and estimated using mapping techniques that largely assess the biophysical processes surrounding dryland degradation.

The most significant dryland problems are particularly pervasive in the arid drylands in the north-west of India. The arid region of India is spread over 38.7 Mha area, out of which 31.7 Mha is under the hot arid zone and 7 Mha under the cold arid zone. Around 62% of India's hot arid zone lies in the state of Rajasthan[29] (Moharana et al., 2016).

3.2 Rajasthan: 'The land of the kings'

> *"While contemporary Rajasthan sits on the periphery of India, in the time before partition, the region was the central highway through which contesting civilisations and political systems travelled and fought. Successive periods of hegemony introduced new vocabularies of property and control over forest and pasture. In each case, however, older systems were not altogether eliminated, but were instead overlain by new forms. The roots of contemporary institutions, therefore, are distinguishable in more remote layers of history".* Robbins (1998: 415-416)

Rajasthan is India's largest state, with an area of around 34 Mha (Singh et al., 2010). It is situated in the north-west with a politically charged border with Pakistan. The state of Rajasthan was formed in 1949, after Indian independence, through a union of twenty-two former princely states, ruled mostly by '*Rajput'* kings, and known during British India as '*Rajputana'* (Gupta, 2016). Rajasthan, literally translates into, 'the land of the kings'. Largely due to its geographic location, the state has a turbulent history beginning in the sixth century AD with the emergence of warrior clans – the *Rajputs* (sons of kings), and their battle for power in the region, against the Mughals of Persia, the Marathas of peninsular India, and finally the British. Warfare was endemic and no one ruler captured power for long enough to make a significant impact for the benefit of the people or the landscape. Some historians claim that some rulers discouraged development in the area in order to avoid attracting unfriendly attention from neighbouring kingdoms (Malhotra & Mann, 1982).

Rajasthan's distinctive social and cultural history is reflected even today, through steadfast traditions, more so in its far-flung western rural areas. When compared with the rest of India the state has grappled with high levels of poverty, gender discrimination, poor literacy and poor health, since its formation. Even today, Rajasthan performs poorly in the Human Development

[29] The rest of India's hot arid zone lies in the state of Gujarat, south of Rajasthan. The cold arid zone is located in the north-east of India.

Index (HDI) rankings (12 of 17 major states of India) (Suryanarayana et al., 2011). Despite sustained economic growth over the past decade and a reduction in Rajasthan's overall poverty rate, the spatial concentration of poverty is high in areas close to barren lands or near forest areas, typically in the rural fringes of the state, where most of the population lives (Bhandari & Chakravarti, 2015).

Its many social development concerns notwithstanding, the greatest threat to Rajasthan's future is often cited to be water scarcity, giving the state the moniker, "*Marushtlai*" or 'region of death' (Sharma & Mehra, 2009). While the eastern part of Rajasthan has hilly tracts and flood prone plains; a majority of the state is arid, with low and erratic rainfall (average rainfall ranging between 250 mm–350 mm), high temperatures, sandy soils and scrub vegetation. The state includes a greater part of the Thar desert (also called the Great Indian Desert).

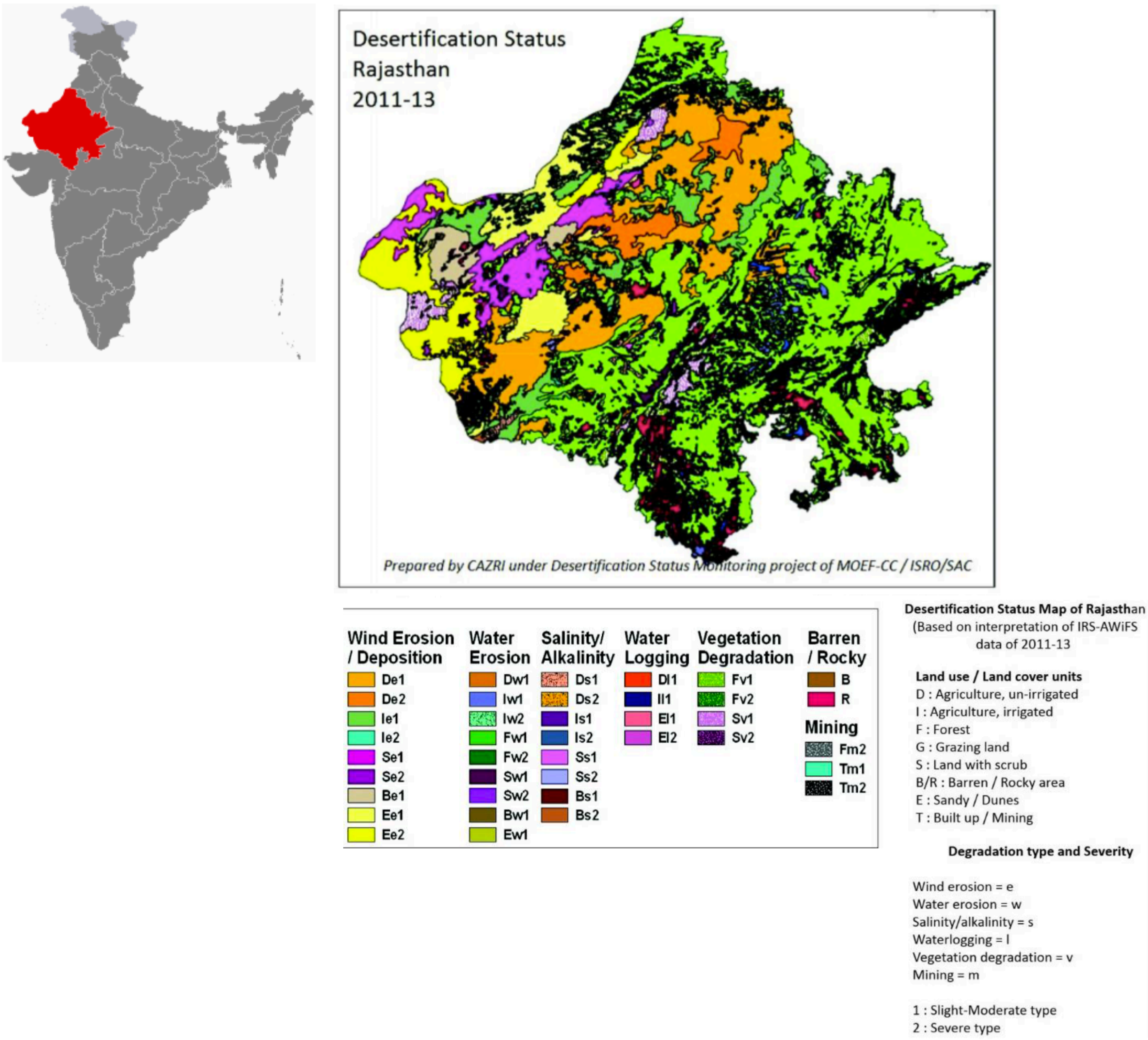
3.2.1 Researching dryland degradation in Rajasthan

According to the NRSC, around 63% of Rajasthan's 34 Mha is currently undergoing 'desertification', with 68% of the area affected undergoing moderate to severe degradation. An analysis of satellite data from the NRSC study (shown in Figures 3.3a and 3.3b) illustrate the major processes leading to desertification and severity within the state. Wind erosion is a key contributor to degradation (45% area affected) followed by vegetation degradation, water erosion and salinisation. Figure 3.3a illustrates that the eastern parts of Rajasthan are prone to vegetation degradation, while the western parts are affected by wind erosion. A study by ICRISAT finds aridity between 1970-2004 to be spatially increasing in Rajasthan (Jodha et al., 2012).

Impacts of the combined effects of dryland degradation and water scarcity are particularly intense in this region due to its high population (200 people/sq.km) and livestock density (150 livestock/sq.km), which continue to increase (GoI, 2011a). During the twentieth century, the human population in Rajasthan increased by 400% and the livestock population by 127%, making the region potentially the most populated arid zone in the world (Varghese & Singh, 2016). This challenges key principles of the 'drylands syndrome' (Reynolds et al., 2007) presented in Chapter Two, where drylands are characterised as regions with sparse populations. A majority of Rajasthan's population (75%) live in rural areas and depend primarily on agriculture for employment, income and food security (GoI, 2011a).

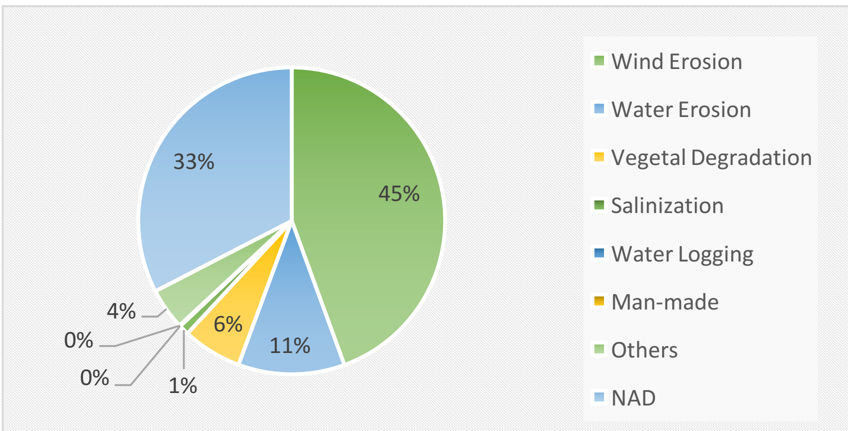
It is evident from the information presented thus far that the government has made efforts to estimate the extent of land degradation in India. Going forward, the Government emphasises its intentions to continue monitoring the extent and spread of degradation through regular mapping exercises, as part of its obligation to the UNCCD (MoEFCC, 2015b). However, little research currently exists, on the multiple factors leading to and exacerbating dryland degradation, particularly in the arid zones of India.

Figure 3.3a: Desertification status map of Rajasthan by degradation type and severity, inset is location of Rajasthan within India



Source: Mohrana et al. (2016)

Figure 3.3b: Key processes of desertification: % contribution to degraded land in Rajasthan



*Source: Derived from data from GoI (2013) *NAD refers to no apparent degradation*

The stock image - represented in some of the literature on arid zones in India - is that of rural farmers in the Thar desert struggling to cope with drought; their growing human and livestock populations invariably degrading the surrounding natural resources. For example, poverty levels and overpopulation are often cited as general motivations for intensive cropping and over-grazing, leading to degradation (Narain et al., 2006; Kar 2014b; Varghese & Singh 2016; Singh & Kumar 2014; CAZRI 2007). Varghese and Singh (2016) in a study in Rajasthan, find correlations between districts with poor human development indicators and increasing area under 'desertification'. The results are however inconclusive due to inconsistencies within and between the districts studied (ibid.). Kar (2014a) in an effort to highlight the socio-economic drivers behind 'desertification', cites examples of indiscriminate intensification, concluding that economic considerations override environmental considerations among local farmers in arid Rajasthan.

In India, analysis of existing research shows that the focal point of most assessments of dryland degradation (e.g. NRSC, NBSS&LUP) lie in the biophysical indicators. While it is important to identify the extent of land degradation in the context of India's arid drylands, there is little concurrent research in diagnosing the socio-ecological constraints and strengths of drylands. People are rarely at the centre of analysis, despite being singled as the sole drivers of dryland degradation. As discussed in Chapter Two, global drylands research has identified the dangers of singling out people as principal drivers of degradation (Behnke & Mortimore, 2016).

Kar (2014b) states that little information exists on the socio-economic drivers of dryland degradation in India. The few studies that have made attempts to incorporate socio-economic variables (such as poverty), show that the correlations are not universally robust. A multivariate analysis by Reddy (2003) is one of the few systematic attempts to ascertain the determinants of land degradation in India (Mythili & Goedecke, 2016). Results indicate that although poorer areas are more prone to degradation, there is no direct evidence that population pressure and poverty lead to degradation. The author instead finds it likely that populated regions are less prone to degradation, due to better carrying capacity of lands that support higher population densities in India. Jodha (1988) found similar results in a household study across Rajasthan; the more (poor) people depending on a portion of land, the greater their motivations to conserve it.

Studies such as these are however limited and the dominant narrative remains that of exploitation by poor farmers and pastoralists. The absence of research into India's arid landscapes and societies has in turn contributed to the lack of appropriate policies and frameworks for governing resource use in the arid zones in India. The next section traces some of the key policies and programmes that administer and govern land use practises in Rajasthan.

3.2.2 Governing land in Rajasthan: Land use policies, governance frameworks and programmes

Several land use policies and related programmes of the Government of India are framed and implemented in line with the socialist policies of India's constitution: to protect people's rights and provide them with support services such as institutional credits, crop insurance, and seed subsidies among others. Over time, these policies have contributed to the greater reach of agriculture. However, they have been unable to curb land degradation processes perhaps due to a lack of foresight and due to persistent problems of implementation.

Two central tenets of land reform in the Constitution of India (1952) are under Article 39: (1) ownership and control of resources should be distributed as best to serve the common good and; (2) operation of economic systems should not result in a concentration of wealth or a means of production to the common detriment (Deshpande, 2007). Land as per the constitution of India is a subject of state legislation, in this case the Government of Rajasthan. The central government issues guidelines, in compliance with the constitution, and plays an advisory role. The state government formulates land policies and makes resources available for rural local governmental institutions to implement under the Panchayat Raj system[30]. The Panchayat Raj Institutions (PRI) include a network of district, sub-district (tehsil or block) and village-level committees and stakeholders (Singhal, 2015). Figure 3.4 shows the hierarchy of the decentralised administrative structure of the government.

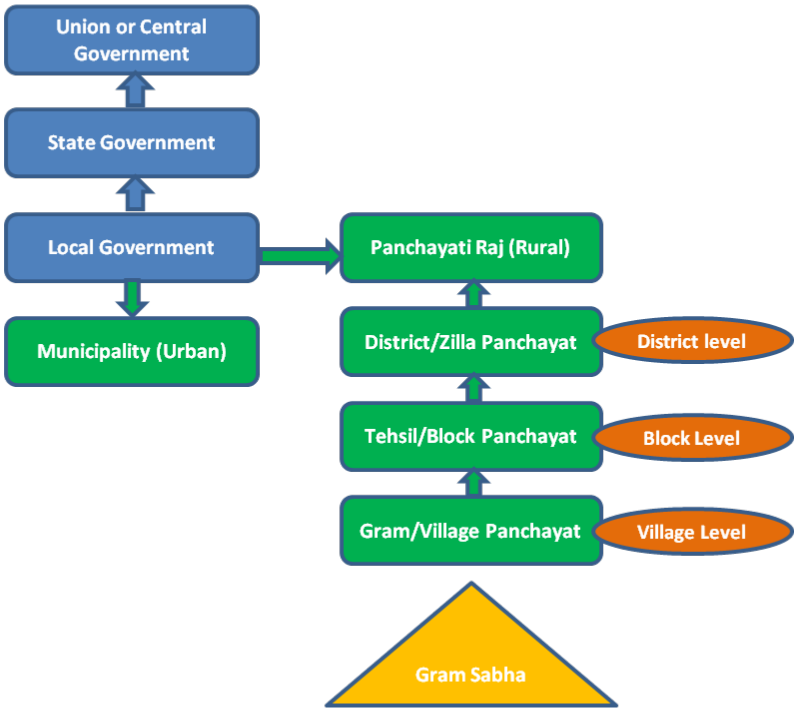
Prior to the British rule in India (1858-1947), there existed a land revenue system in Rajasthan where ownership of land clearly rested with the rulers, chieftains and *Jagirdars*[31]. They appointed intermediary revenue collectors or *zamindars*[32], who collected land revenue from those cultivating the land (tenants) (Gupta, 2016). While the British continued this system, they made *zamindars* proprietors of the land, collecting tax from tenants, which created a rural elite of non-farmer intermediaries. This *zamindari* system, which exists to this day (although informally) increased land revenues, and led to insecurity of tenure among the tenants and tillers. Tenure insecurity in turn limited access to support and extension services, such as credits and insurance, which were typically available only to landowners. Tenants had to invest their own money/resources to improve the land they tilled (Sud, 2007).

[30] The term panchayat literally translates to 'meeting of five people'

[31] *Jagirdars* are recipients of parcels of land in return for their military services and hold rights to the land and all revenue from it.

[32] Derived from the Hindi word *zimmedar* meaning the one who is responsible for – in this case - revenue collection.

Figure 3.4: Hierarchy of the decentralised administrative structure of the Indian Government[33]



Source: Author's own

At the time of independence (1947), this complex socio-economic and multi-layered feudal agrarian structure posed a major challenge for planning in the new Republic of India. Land, in the large, densely populated state of Rajasthan with a predominantly agrarian economy was a priority. Rajasthan subsequently was one of the first states of independent India to take on land reforms (Jodha, 1982). In 1952, the state legislative assembly passed the Rajasthan Land Reforms and Resumption of Jagirs Act. Following this, the Rajasthan Agricultural Land Utilisation Act (1954), Rajasthan Tenancy Act (1955) and Rajasthan land revenue rules (1957) were introduced. These acts helped tenants who were the actual tillers, to acquire the status of *khatedar* (account holders). They were granted 'heritable and transferable rights' from the *zamindars* (true owner). The acts stated that *zamindars* can lease land to *khatedar* tenants for a maximum period of five years with an interval of at least two years between one lease and another (GoR, 1957). The interval of two years was included to promote land reclamation after

[33] India is a democratic country, where the federal system of Governance has the Central or Union Government under which the State Governments share responsibilities, yet remain independent in internal affairs. Local Governments function under the State Governments and are decentralised, as per the constitution of India (73rd amendment, 1993). The Local Governments for Urban areas are municipalities and rural areas are Panchayats Rural Institutions (PRI) also called rural assemblies. PRI is a three-tier structure: Gram Sabha or the village assembly and is made up of the following: (i) Village or Gram Panchayat is the basic PRI unit at a village level; (ii) this is followed by the Tehsil or block panchayat (sometimes referred to as Panchayat *Samiti*), which is an assembly of all the (village level) Gram panchayats of that administrative block. If a Tehsil is large and difficult to administer, they are likely to be two or more sub-tehsils or Panchayat *Samitis* (iii) The block panchayat or Panchayat Samiti is a link between the Gram Panchayat and the third tier of the PRI, which is the District or Zilla Panchayat.

intensive cultivation (in line with traditional land management practices). The *khatedar* could in turn lease land to a *Ghair-khatedar* or sub-tenant for only one year. The aim of these policy interventions was to:

- Abolish the power given to intermediaries, so farmers could keep income from land;
- Reform tenancy rights so small and marginal farmers had control over the land they tilled;
- Fix ceilings on land holdings, so few farmers were not in control of majority cropland; and
- Build a sound system of land records for better revenue administration.

There have been amendments to these land policies over the years but changes have essentially been slight modifications of the original policy. For instance, the Land Acquisition and Rehabilitation and Resettlement Bill, introduced first in 2011 and adopted by Rajasthan in 2014, was described as a 'major reform'. However, Ghatak & Ghosh (2011) were of the view that is a slightly altered version of the colonial Land Acquisition Act of 1894[34].

Common lands or common property resources (CPRs), such as pasture lands, hold intrinsic value to the pastoralists and semi-pastoralists in Rajasthan. In 1955, the State Government shifted management of CPRs entirely to the village *Panchayat* (PRIs). These CPRs, known locally as *Orans*, *Gochars*, *Birs*, were governed under the name 'permanent pastures', but the capacity to generate revenue from these lands was abolished altogether (Gupta, 2016). Thus, there was no restriction put on their use, and within a short time almost all CPRs had lost their trees, shrubs, and grasses. Informal *panchayat* agreements came to be, that resulted in pastures being illegally occupied or sold off to private industries.

Recognising the significance of land to its people, all 12 of India's five-year plans (developed by the National Planning Commission, Government of India[35]) have included land reforms as a vital component. In 2015, the Planning Commission of India was replaced with the National Institutions for Transforming India (NITI Aayog). NITI has been introduced as a bottom-up participatory planning alternative to the perceived top-down approach of the Planning Commission (Pathak, 2015). In principle, it aims to increase the role of state governments, civil society, and rural stakeholders in policy making. The NITI in particular singled out old tenancy

[34] The Land Acquisition Act of 1894 allows easy acquisition of land from individual landowners for public purposes by the government. A generically determined monetary value is assigned by the government agency acquiring the land and paid to the landowner in compensation to cover losses from surrendering the land. In India, after more than a century, it was only recently replaced and called the Right to Fair Compensation and Transparency in Land Acquisition Rehabilitation and Resettlement Act (it was introduced in parliament in 2011 and passed in 2013).

[35] The planning commission of India was a key institution in the government of India, formulated after independence to develop India's Five-Year plans. The first Five-Year Plan was launched in 1951, focusing mainly on development of the agricultural sector.

laws as restrictive, and introduced a Model Agricultural Land Leasing Act 2016, so as to better manage leasing rules on land, such as providing lessee-cultivators with equal entitlements to loans, crop insurance, and disaster relief, previously available to land owners only (Mani, 2016). While the central government proposed this act, the state of Rajasthan state is yet to adopt it. The impact and relevance of these changes to communities will be discussed in Chapter Five.

There are many other policies that have impacted on land and allied resources, such as the Rajasthan State Environment Policy 2010, and the State Forest and Afforestation Policy 2010 amongst others. In addition, the Central and State governments have introduced several programmes in Rajasthan to promote agriculture and increase land productivity such as the National Food Security Mission, and the National Mission on Sustainable Agriculture. Drylands-focused programmes introduced include:

- Drought Prone Areas Programme (DPAP), later integrated into the Desert Development Programme initiated in 1977-78 in hot and cold desert states. The focus was on restoring the ecological balance of desert lands through sand dune stabilisation, shelterbelt plantations and silvi-pasture development in the large tracts of hot sandy desert areas in ten districts of Rajasthan.
- Rainfed Area Development Programme (RADP) under the larger National Agriculture Development Scheme (Rashtriya Krishi Vikas Yojana), initiated in the year 2011-12, it offers a complete package of activities to farmers especially, small and marginal farmers in order to improve their quality of life.

For the arid region under study, the government became a ratified member of the UNCCD in 1996; the Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal ministry of India's UNCCD. To highlight their intentions and awareness of the significance of land degradation to addressing developmental concerns, the Government of India announced in 2014 an ambitious programme to combat the challenge and make the country 'land degradation neutral' by 2030 (GoI, 2014). However, no specific policies or programmes to achieve this ambition have yet been made public. A few programmes exist, such as the National Agricultural Research Project (NARP) (2005); it aims to sustainably increase agricultural productivity through site specific research in each agro-climatic zone, based on soil type, temperature, rainfall (agro-meteorological characteristics) and geologic constraints (Chinnasamy et al., 2015). However, information on the implementation and specific reach of such programmes are difficult to unpack due to poor and inconsistent data.

Overall, while land reform has remained at the forefront of both central and state government agendas since the formation of Rajasthan, confronting land degradation is a relatively new challenge for the government. Policies tackling land reform are therefore often in direct opposition to those aiming for sustainable land management. For instance, with some exceptions, a majority of India's agrarian policies and programmes continue to be oriented towards increasing crop productivity. As a result, they typically neglect principles of conservation, needed to achieve land degradation neutrality. Jodha (1982) posited that the neglect of conservation is partly due to poor political payoff in the context of the immediate socio-political objectives of land reform. This evidently continues to be a problem in designing sustainable land strategies for rural dryland agro-ecosystems. An examination of the role played by policies in land use, land management and vulnerability warrants further research and will be addressed in later chapters.

Thus far, this chapter has explored the challenges facing drylands in India, narrowing down to the largely arid state of Rajasthan. Policy planning in India correctly acknowledges the significance of land policies and land reform as a means to ensure sustainable and equitable development. The decentralised nature of India's governance also acknowledges that the diversity of the country cannot be governed by universal and generic administration. However, governance in India faces significant constraints in implementation due to an inadequate focus on the context within which agriculture is practised, especially in the arid regions. Having established the diversity that exists within the drylands of India and the challenges of gaining adequate perspective within these varied landscapes, the following section introduces the arid zone district of Jodhpur as the site for empirical study.

3.3 Jodhpur: The site for empirical study

The focus of this study is the district of Jodhpur which is reflective of the wider arid region of Western Rajasthan, where aridity is most severe.

Jodhpur covers an area of 22,850 sq.km and has a population of 3.68 million (GoI, 2011b). For the purpose of administration, the district is divided into seven blocks or *tehsils* (block panchayats). These are Osian, Shergarh, Jodhpur, Bhopalgarh, Luni, Bilara, and Phalodi. Three of the larger tehsils (Shergarh, Osian and Phalodi) are further divided into sub-blocks (also called *Panchyat Samithi*) for administrative convenience to aid the implementation of rural development projects and schemes[36]. The district thus has ten *Panchayat Samithis* governing over 1,838 villages distributed across the seven *tehsils* (ibid). Budgets of the districts are transferred to the *Panchayat Samithis* who have the authority to utilise funds as they choose within the confines of the specific purposes that the funds are allocated for. Figure 3.5, provides an illustration of the location of Jodhpur district and seven *tehsils*.

[36] Shergarh is divided into Shergarh and Balesar; Osian is divided into Osian and Bawari; Phalodi is divided in Phalodi and Bap.

Figure 3.5: Location of seven Jodhpur *tehsils* (blocks) within Rajasthan

Source: Author's own

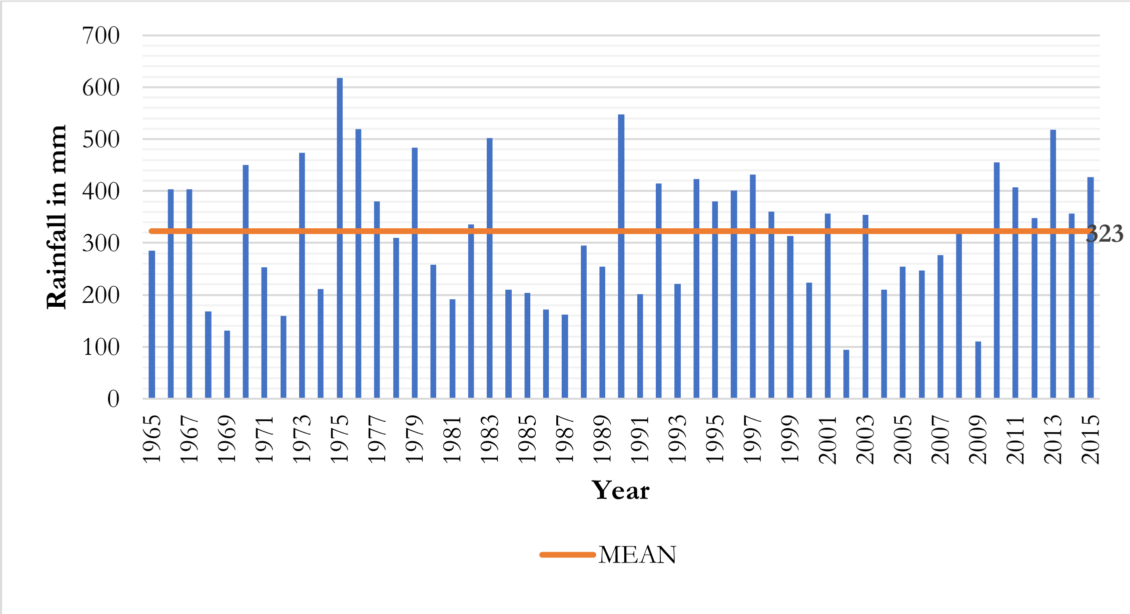
3.3.1 Present-state of environment and natural resources in Jodhpur

Most of the district of Jodhpur is located in the arid western plain while a small portion of the south-eastern area (around 14%) is located under the transitional plain of the Luni Basin (GoR, 2013). Key natural parameters of resource use in the region are discussed below[37].

Rainfall: This is one of the most arid regions of India. Annual rainfall is low, variable, and scattered and ranges between 216 and 496 mm. The mean annual rainfall is 323 mm (Figure 3.6) and approximately 80% of the total annual rainfall is received during the monsoon months (June, July, August and September) (JJAS), with an average of 15 days of rainfall per year (GoR, 2013).

[37] It is important to note that trends in resource-use and resource degradation, including climatic parameters form a significant crux of the research and are discussed throughout this thesis. Consequently, the information presented here only provides a cursory look at some of the features that may prove essential to the discussions conducted later in this chapter.

Figure 3.6: Annual Rainfall in Jodhpur district (1965-2015) (in mm)



Source: Derived from IMD data (2016)

Temperature: The district is characterised by high summer and low winter temperatures. The maximum and minimum temperatures are 46°C and 2°C during the summers and winters respectively. Winters are of short duration, not exceeding two months - December and January. Both summers and winters have large diurnal and spatial variability. Mean daily Relative Humidity is around 51% (1990-2009) and evapotranspiration is one of the highest in Rajasthan (ibid.).

Land forms and soils: Land elevations in western Rajasthan vary from 30m to around 300m above Mean Sea Level (msl) and are characterised by arid land forms (GoR, 2009). The area is covered by aeolian, alluvial and buried channels[38], sand dunes, and inter-dunal plains. Small to medium-sized saline water depressions also occur in the western parts (Kar, 2014d). These depressions are responsible for the occurrence of evaporite deposits that have an influence on the regions groundwater quality (discussed below). The Thar Desert occupies a major portion of Jodhpur district.

Soils in the area are classified as sandy and loamy. Broadly, soils in large parts of the western plains and dune-covered areas of Jodhpur are deep, excessively drained, calcareous, or non-calcareous sandy (Shyamapura et al., 2003). Table 3.1 presents the soil loss classes from negligible (soil loss less than 5 t/ha/year) through to very severe (soil loss of 40-80 t/h/year); it shows that over 50 percent of Jodhpur's TGA is subject to moderate to severe erosion.

[38] Aeolian processes pertain to wind-related processes (i.e. transportation of sediments and deposition from one location to another) that shape geology and climate of the region. They produce sand dunes and ripples.

Around half of Jodhpur district experiences soil loss in excess of the tolerance limit[39] of 11.2 tonnes/ha/year.

Table 3.1: Soil erosion classes in Jodhpur district as calculated by NBSS&LUP (2003)

	Soil Erosion Classes				
	Negligible (<5 t/ha/yr)	Slight (5-10 t/ha/yr)	Moderate (10-15 t/ha/yr)	Severe (15-20 t/ha/yr)	Very Severe (40-80 t/ha/yr)
Area degraded (in sq km)	4480	5815	6362	5900	0
Percent of Total Geographic Area of Jodhpur	19.6	25.4	27.8	25.8	0

Source: Shyampura et al. (2003)

Important determinants of land degradation in Jodhpur are soil loss accompanied by nutrient loss of the key elements of Nitrogen and Phosphorus, which are required for land productivity. Table 3.2 shows the content of Nitrogen (N), Phosphorous (P) and Potassium (K), collated from GoR's agricultural reports. The level of nitrogen in the soil has reduced from medium to low since 2010; while the level of Potassium has shifted from high to medium since 2009. The GoR (2015) also recognises problematic soil in the district, which includes 2,902 ha of saline soil and 9,527 ha sodic or alkali soil. The implications of saline and sodic soil on land productivity are discussed in Chapter Five.

Table 3.2: Fertility status of key soil nutrients in Jodhpur district, Rajasthan (2007-2015)

	Nitrogen (N)	Phosphorous (P)	Potassium (K)
2007	M	M	H
2008	M	M	H
2009	M	M	H
2010	L	M	M
2011	L	M	M
2012	L	M	M
2013	L	M	M
2014	L	M	M

Source: Collated from Govt. of Rajasthan (2007-2015); L = Low; M= Medium; H = High

Natural vegetation: Due to water scarcity, vegetation in Jodhpur is largely seasonal. With the first rains in June/July, a few grass species grow and shrubs and trees become green. But soon

[39] Tolerance limit is calculated by the NBSS&LUP and is defined as the maximum level of erosion that will permit crop productivity to be sustained (Shyamapura et al., 2003: 16).

after the retreat of the Monsoon in mid-September the vegetation dries leaving only a few perennial shrubs and a thin cap of pale grass on the landscape (Kar, 2014a). Important species of trees and shrubs observed during the field visits include Khejri (*Prosopis cineraria*), Rohida (*Tecomella undulata*), Desi Babul (*Acacia nilotica*), Kumat (*Acacia senegal*), Neem (*Azadirachta indica*); a few shrubs of Bordi (*Ziziphus nummularia*), Kair (*Capparis decidua*) and Jal (*Salvadora persica*); and grass species like Dhaman (*Cenchrus ciliaris*), Sewan (*Lasiurus sindicus*), Gramna (*Panicum antidotale*) (GoR, 2009). In addition, the non-native species of Angrezi Babul[40] (*Prosopis juliflora*) is prominent in all areas of the district. Trees in the region are the major source of food, fodder and shelter. Leaf litter is used to fertilize the land; scrub vegetation is used to graze cattle, small ruminants (sheep and goats), and camels. *Khejri* and *rohida* are the two most important multi-purpose woody trees of traditional agro-forestry systems. The wood is used for firewood; the timber for housing, furniture, agricultural implements; edible fruits, seeds, gums, roots and flowers are used in cooking preparations, and for their medicinal value (Picture 3.1).

Picture 3.1: Use of various tree components from local *khejri* and *rohida* trees in construction: view from the outside (left) and view from the inside (right) the house

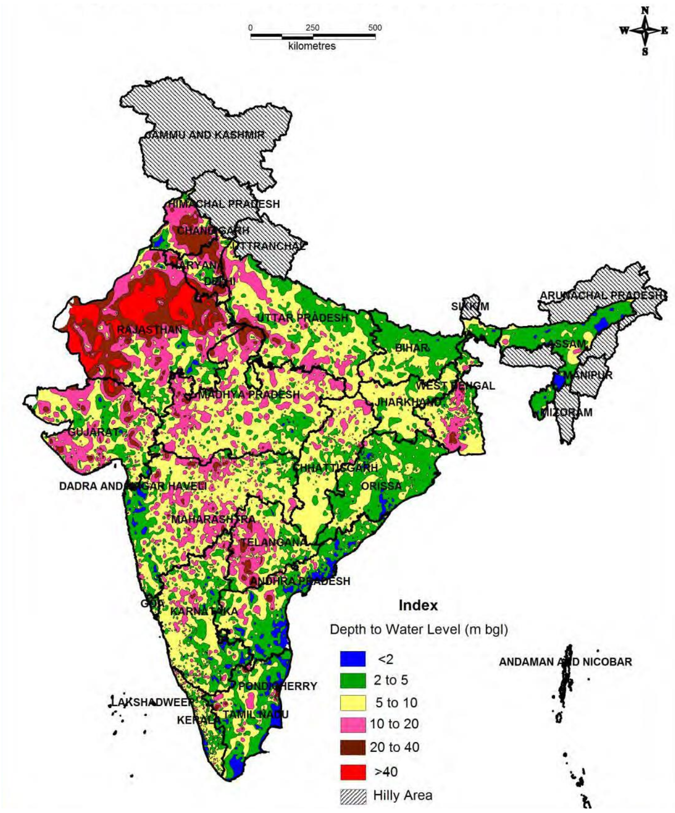
Source: Author's own

Surface water and groundwater resources: Due to the location of the district, drainage systems are not well developed. There is a single river - the Luni - that flows seasonally through the south-east of the district (GoR, 2013). The limited availability and distribution of surface water places the groundwater resources under stress. The net irrigated area[41] in the district is around 25% of the net sown area, and 97% of irrigation is through tubewells, which draw on

[40] Angrezi Babul – translates into foreign or English Acacia, referred to as such by locals due to the non-native, often invasive Mexican-origin *Proposis juliflora.* Acacia nilotica on the other hand is referred to as Desi Babul – 'local' Acacia.
[41] Net Irrigated Area: It is the area irrigated through any source once in a year for a particular crop (see Appendix I).

groundwater. A large part of groundwater resources are deep, brackish and saline, with high fluoride concentration in places, which makes it unfit for drinking and for irrigation (CGWB, 2016a). Consequently, areas with fresh groundwater have reached high stages of utilisation; some parts of Rajasthan have witnessed utilisation of more than 200% of the replenished yield of groundwater. The depth to water level presented in Figure 3.7 illustrates that groundwater levels in the west of Rajasthan are critical, with the level in large sections of the state, especially the area around Jodhpur at 40m below ground level (CGWB, 2016b).

Figure 3.7: Depth to water level map of India (January 2016)



Source: CGWB, 2016a

Furthermore, Central Ground Water Board (CGWB) measurements in various locations around Jodhpur district showed that, against an annual recharge of 393.13 million cubic meters (MCM) the groundwater extraction is 660.9 MCM. This results in a negative balance of 267 MCM of groundwater in the district. Out of the nine blocks[42] selected for assessment by the CGWB, five have already become overexploited zones with an annual stage of exploitation of 147 to 286 percent (Table 3.3). Local government officials refer to these over-exploited zones as 'dark-zones'. Within these dark zones, the extraction of water by new tubewells need prior authorisation by the CGWB.

[42] Boundaries of districts, blocks and villages change consistently in India as indicated in Chapter One. Studies using information and data from different time periods will thus show different block and tehsil formulations. The information in this table was collated using data from 2010 and therefore does not align with current divisions of blocks under each tehsil.

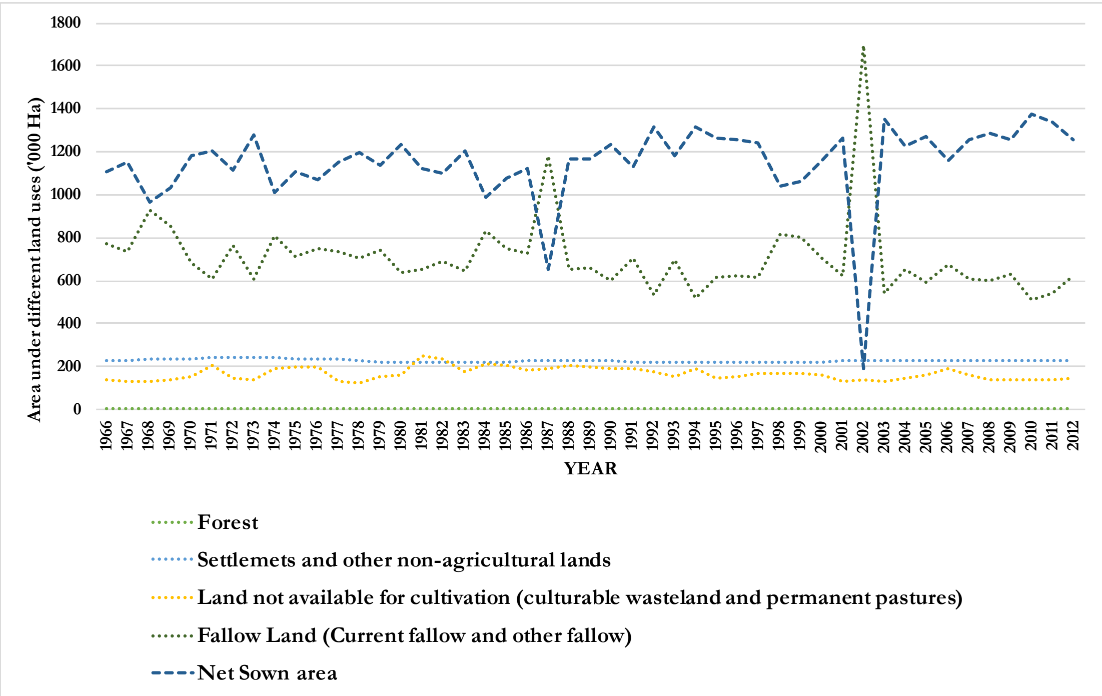
Table 3.3: State of groundwater resources in Jodhpur (2013)

Tehsil		Net annual groundwater recharge (MCM)	Annual draft (MCM)	Net groundwater balance (MCM)	Stage of exploitation (%)
Phalodi	Bap	65.71	9.86	55.85	15.00
	Phalodi	51.49	36.42	15.07	70.7
Osian	Osian	69.28	198.30	-129.02	286.2
Shergarh	Shergarh	33.22	26.83	6.39	80.8
	Balesar	19.14	28.30	-9.16	147.9
Bhopalgarh	Bhopalgarh	56.12	149.06	-92.94	265.6
Bilara	Bilara	48.53	138.03	-89.50	284.5
Jodhpur	Luni	22.08	15.02	7.06	68.0
	Mandore	27.57	59.02	-31.47	214.1
Total		393.13	660.87	(-)267.77	168.1

Source: CGWB (2013)

Land use patterns: The total reported area of the district as per land utilisation statistics[43] is 2,256,405 ha. Approximately 56% of this area is sown[44] and around 28% is under fallow. Area under permanent pastures and grazing land is low at 5% of TGA, and the area under forests is less than 1% of TGA (GoI, 2012). The land use pattern of Jodhpur district from 1966 -2012 is given in Figure 3.8.

Figure 3.8: Land utilisation pattern in Jodhpur district, Rajasthan (1966-2012) ('000 Ha)



Source: Collated from GoR (2013)

43 Appendix I provides definitions of all land use management categories defined by the Government of India.
44 Calculated as Net Sown Area, which is the area of crops grown in a given season

3.3.2 Key socio-economic factors

The key socio-economic variables of Jodhpur are summarised in Table 3.4, and are contrasted with averages for Rajasthan and the rest of India. Variables of note include low irrigated area, high population density and growth rate, poor literacy rate (especially for women), and a skewed gender ratio. Agriculture is the main source of income for the 66% of Jodhpur's rural population (GoI, 2011a). Within rural areas, there is significant unequal growth between the remote areas of the west and more peri-urban areas of eastern and central Jodhpur (ibid.). Several key social and economic indicators of development in Jodhpur lag behind both the state (Rajasthan) and the national level.

Table 3.4: Key socio-economic variables of interest

	Jodhpur	Rajasthan	India
Population density (population/km²)	161	200	383
Decadal population growth (%)	28	21	17
Rural population (%)	66	75	70
Literacy rate (%)	65 (M-78; F-51)	66 (M-82; F-65)	74 (M-82; F-65)
Gender ratio (females/1000 males)	916	928	943
Proportion of Scheduled caste/ Scheduled tribe (SC/ST) (%)	20	31	25
Proportion of workers in agriculture	56	62	51
Work participation rate (WPR) (%)	40	32	39
Female WPR (%)	20	21	25
Cultivators* (%)	40	45	31
Agricultural labourers* (%)	16	16	NA
Livestock units per person	0.93	0.86	0.75
Percentage irrigated area to total cropped area (3-year average)	22%	26%	48%
Average land-holding per household (in ha)	3.07	3.38	1.16
Per capita income	USD 260	USD 354	USD 1461

*Agricultural labourers work on land but do not own their own land. Cultivators are farmers with land entitlements.

Source: GoI (2011a)

Hindus are the religious majority in this region with more than 150 clans, castes, and sub-castes. The traditional view of caste in Hindu society is that it operates along a single hierarchy from *Brahmin* (priests and teachers), *Kshatriyas* (warriors and rulers), *Vaishyas* (farmers, traders and merchants), *Shudras* or *Dalits* (labourers) and *Ati Shudras* or 'untouchables' (sweepers, cleaners) (Dumont, 1970). In reality, caste is not as clear cut and nuances of caste in the study area will be discussed in Chapter Six. Major sub-castes in Rajasthan include: *Rajput, Brahmin, Jat,* *Bishnoi, Kumhar, Dewasi*, in addition to SC/ST[45] sub-castes such as *Meghvals*. Muslims are the second most dominant group and include: *Sheikhs, Pathans, Maves and Sayyid*. Villages in Jodhpur include populations that are a mixture of various religious castes and sub-castes. Caste is one of the main social factors determining distribution of houses and maintenance of intra and inter-household relationships.

When compared to men, women have poorer access to resources, services, and institutional support mechanisms. Rajasthan in general, and more specifically the western districts, including Jodhpur are heavily steeped in patriarchal primacy and remain so to this day. The position of women is reflected in a skewed gender ratio, inadequate access to education and lower work participation rates than men (Table 3.4). Discrimination is manifest in many more ways and includes female foeticide, dowry system, feudal customs and values, conforming to the *purdah* (veil covering the face), child marriage, exclusion from public life and politics, and social polarisation along caste lines. Crucially, women have limited access to land ownership.

As evidenced in this section, in addition to its harsh physical environment, the district of Jodhpur is set within the geography of a more complex socio-economic panorama. Much like the larger state of Rajasthan, where it is situated, the district of Jodhpur has a rich, varied, and turbulent history that has contributed to its culturally diverse social environment. Strong adherence to tradition, codes of chivalry, and the complex language of caste are strong leitmotifs of the district, and play an integral role in natural resource management. Tracing histories of resource use and in particular identifying the cultural and social origins of resource-use practices in the area are therefore of utmost relevance to the central aim of this thesis and will be discussed in the following section.

3.4 *From Tobas to tubewells:* A brief history of social and agrarian change in Jodhpur

Studies have shown that land use change varies depending on the complex interactions between historical legacies, the physical characteristics of land, societal and cultural value and all of which shapes how the land is managed (Tomei & Helliwell, 2016). This section traces the agrarian history of the region, from being a water-scarce region pre-independence, to extension of agriculture through the growth and hegemony of the Green Revolution post-independence, and including the present day challenges posed by dryland degradation and climate change.

[45] Scheduled caste (SC) and scheduled tribes (ST) are officially designated groups of historically disadvantaged groups of people (socially and economically) in India. The terms are recognised and set by the Constitution of India, providing these groups with certain special reservations in many of Indian sectors including education, politics, so as to guarantee representation. The SCs are typically from India's lowest castes (at the bottom of the Hindu caste hierarchy), while the STs are typically tribal groups, nomads, and not generally part of organised religion, generally considered outcastes.

3.4.1 Role of drought in traditional organisation of society: Pre-1960s

Due to heavy dependence on natural resources for their livelihood, the organisation of society in this region has always been a reflection of resource management. The equitable resource-use and division in the region, is described by Malhotra and Mann (1982: 306).

> This is a self-regulating society where division of labour and patterns of relationship came from the need for a more well distributed use of ecosystem functions that are scarce. Here, resource equilibrium was maintained through functionality of different groups (divided by caste); whereby only the agricultural and pastoral caste put pressure on the land. For instance, the community was divided into two distinct groups, sedentary and nomads. Nomads were pastoralists or tradesmen that journeyed the more western areas, too arid for cultivation. En-route, they sold milk, clarified butter and animals to the sedentary population. If they penned their livestock in the fields during the night, the farmers provide food and money in return for manure. The sedentary population consists of numerous castes which include: agricultural groups (e.g. *Jats*, *Bishnoi*, *Rajputs*); craftsmen (e.g *Kumhar*, *Lohar*, *Darji*); religious practitioners (e.g *Brahmins*, *Sads*); money-lenders and traders (e.g *Mahajan*, *Khatri*); animal husbandry (e.g. *Raika*, *Dewasi* and numerous Muslim groups). This functional specialisation and intricate exchange system not only knitted the society together but facilitated a more equitable use of ecosystem services.

Norms such as early marriage and high fertility rates were built into the social ethos, to prevent families from being wiped out by famine (ibid.). Famine and drought were normal occurrences in this region with a moderate drought expected once every three years (Narain et al., 2006). This led to the development of society, which was adapted to the varying levels and intensities of drought.

While scientists classify droughts into different types, local people in the region classify drought into four categories, which take account of their key resources: *Annakal* (grain famine), *Jalakal* (scarcity of water), *Trikinal* (scarcity of fodder) and *Trikal* (scarcity of grain, water and fodder) (Malhotra & Mann, 1982). *Trikal* is the case for a 'severe drought', where all three of their resources are impacted.

Two local sayings on drought have been selected and translated into English. The first demonstrates the distress caused by drought and the resulting nomadic patterns. The second saying illustrates the reliance of farmers on their traditional knowledge systems in the absence of meteorological information.

(i) *pag Pungal, sar Merta, udraj Bikaner*
Bhulo cuko jodhpur, thavo Jaisalmer

My (famine) "feet remain in Pungal, my head in Merta and my belly in Bikaner; sometimes I can be found in Jodhpur, but Jaisalmer is my permanent residence" (Kachhawaha, 1985).

(ii) *titar pankhi badali, bidhva kajal rekh*
a barase a ghar kare, in mein min na mekh

"Clouds with wings like a partridge and the eyes of a lady with kohl[46] bring rain, without doubt" (Bharara, 1985).

It is no surprise that unique water harvesting, storage, and forage systems were at the centre of traditional societies in anticipation of drought. Some of these indigenous resource management systems are discussed below.

Storage of drinking water: Pond catchment systems of water harvesting for human and livestock use were common and called *Tobas*, *Nadis*, *Johads*, *Baoris* and *Talab*. For instance, *tobas* were dug-out pools in different parts of the village territory constructed to save rainwater in preparation for drought. These were surrounded by a lush growth of grasses, used typically for livestock. *Tobas* were constructed away from the village centre and households divided by caste used different *tobas*. Once a *toba* was exhausted they moved to another one. Only when all the *tobas* were exhausted did the people return to their settlement. To avoid resource exploitation, catchments were never dug too deep, so as to lessen pressure on the range and prevent long-term reduction in vegetation. *Baoris* are stepwells, unique architectural marvels visible across Jodhpur, where wells storing groundwater were built with many layers of steps, constructed to cope with seasonal rainfall fluctuations in availability of water. They also served as places for social gatherings and provided relief from the heat for farmers working in the fields (Picture 3.2). *Tankas* or cisterns for harvesting water were common in all households, while *johads,* or rainwater storage tanks principally for livestock use, were present in every village in the region (Narain et al., 2006; Singh et al., 2010).

[46] Kohl refers to the black powder used by women around their eyes.

Picture 3.2: A disused stepwell (*Baori*) (top) and a surviving *Johad* that stores rainwater for livestock in different parts of the village (bottom)

Source: Author's own

Run-off farming: Soil moisture was exploited to the utmost by the cultivation of '*khadins*', which were natural depressions found in rocky and stony terrain partially filled with fine sediments resulting in the development of localised silty clay-loam and clay-loam soil pockets in otherwise sandy and rocky territory (Prasad et al., 2004). In *khadins,* water flows from shallow rocky surfaces into low lying farmland during the monsoon period. Subsequently crops are grown when water recedes in the winter. These were developed in Rajasthan as early as the 15th century AD by Paliwal Brahmins (Kar, 2014a).

Fallowing practices: Fallowing was a traditional practice which is a form of crop rotation where a portion of land is deliberately not cultivated for between two and five years to conserve moisture and allow the land to regain its fertility (Sinha et al., 1996). Farmers were generally of the opinion that the more parcels of land they held, the greater were their chances of harvesting at least some grain during drought or poor rainfall years. Since land was sown only after it received rain, fragmentation of plots had the advantage of allowing for a greater proportion of the land to be left fallow in dry years. These fallow lands also provided grazing resources for the livestock, which in turn, provided fertilizer to the fields. Before taking up fallow land for cultivation, cluster bean (*guar*) was usually grown in the first year and the land was ploughed three times using camels and bullocks. This was followed by mixed cropping of pearl millet, pulses (i.e. moth and mung bean) and sesame in the ratio of 20:1:1:1 (Malhotra & Mann, 1982). Green manuring with legume crops, mixed cropping, and crop rotation practices helped to maintain and improve soil fertility.

Storage of grains: To prepare for drought, grains were stored, in hermetic earthenware pots and mud/clay silos. These were usually round or cylindrical in shape and had a roof made of thatched grass. These were made using the *Talab* (pond)'s mud mixed with a bit of straw (and/or cow dung). *Kothas* (Picture 3.3), as they are known in Jodhpur, were also used to keep grains as well as milk and curd or any other food items that needed to be kept fresh. These storage systems were laborious to construct, but protected grains from pests, rodents, humidity and other external elements and were capable of supporting households for anywhere between five and ten years.

Picture 3.3: Kothas are still used in some regions to store pulses (left) and fodder (right)

Source: Author's own

These and other traditional adaptations helped communities to survive drought and other harsh climate variations, such as hotter summers, common to the environments in which they lived. Since the 1960s, improvements in water availability in these water-scarce regions have led to changes in the way society has structured itself. These changing practices were largely led by transformations in agriculture and livelihoods brought on by the Green Revolution.

3.4.2 Growth and hegemony of the Green Revolution: 1960-2000s

During India's first decade post-independence, the two key goals were: (i) to achieve maximum increase in agricultural output to support rapid industrialisation and reduce imports, through programmes such as the 'grow more food' campaign; (ii) to reduce disparities in rural life (Mitra, 2011).

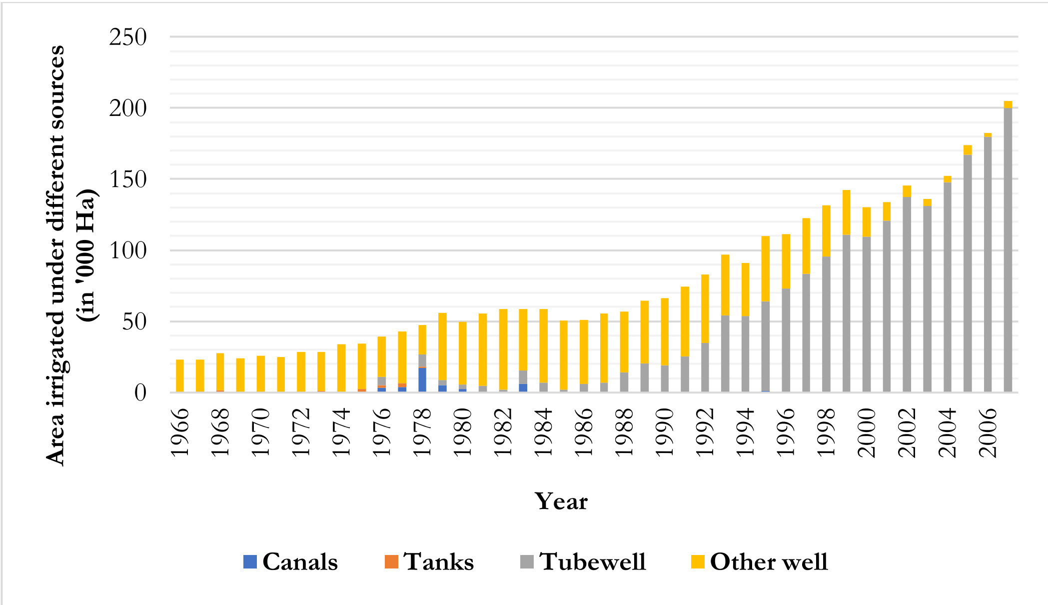
Initiated in the latter half of 1960s, the Green Revolution offered to eliminate the government's conundrum of achieving the two seemingly irreconcilable goals (Frankel, 1971). The Green Revolution has since had a lasting impact on the societies and landscapes of Jodhpur and more broadly, Rajasthan.

The Green Revolution aimed at self-sufficiency in food production, India's major challenge in the 1950s and 1960s. It offered the potential for prosperity and elimination of the drudgery involved in rain-fed agriculture in India's drylands. It focused on improving crop productivity, and the principles of the Green Revolution relied heavily on technology, including irrigation facilities, tractors, high yielding variety (HYV) seeds, chemical fertilizers, and improved farm implements (Singh, 2000). Intensification and extension of agriculture through Green Revolution-led policies yielded significant results over the next 30 years across India with a three-fold increase of grains production between 1965-66 and 1998-99 (Pingali, 2012). A majority of the policies and programmes were focussed on improving the productivity of cash crops, such wheat and rice, in the relatively fertile states of Punjab, Haryana and Uttar Pradesh. Rajasthan, especially its arid west, was not at the centre of the Green Revolution agenda due to the relative low productivity potential of its land.

However, in the arid west of Rajasthan too, irrigation became a major driver of change to support the peasants in rain-fed areas who practiced subsistence farming. The Indira Gandhi Nahal Project (IGNP) (canal) was introduced to bring in water from Punjab, and boost irrigation in this water-scarce area (Kar, 2014a). While the canal did not reach the district of Jodhpur, it brought with it the promise of water prosperity in the wider region. It was followed by rural electrification programmes and subsidised agro-technologies (e.g. subsidies on diesel pump-sets, HYV seeds, and chemical fertilizers).

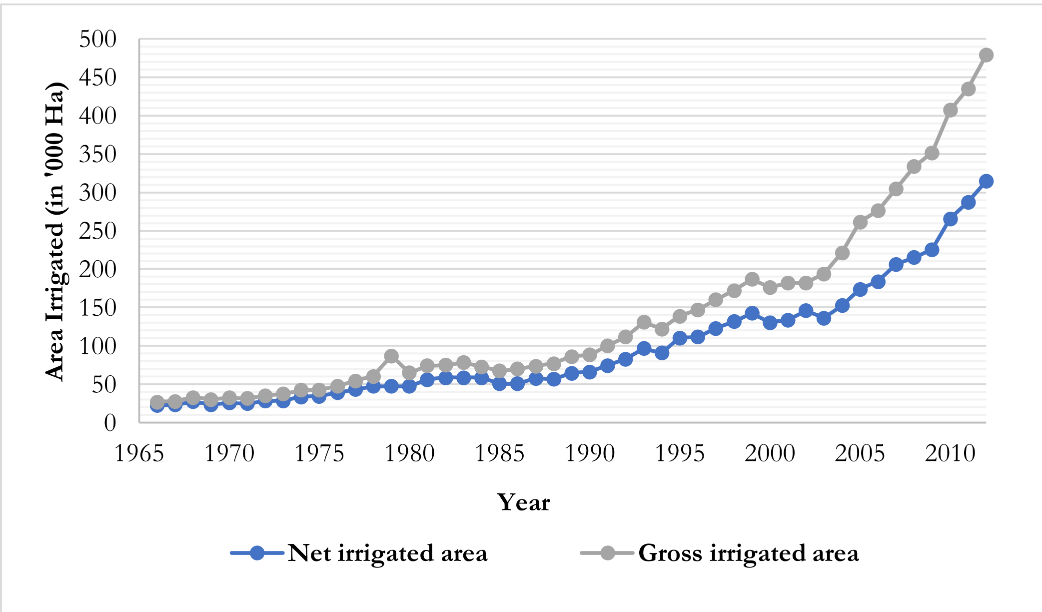
Irrigation using surface and groundwater became a major driver of change in agricultural land use over large parts of arid Rajasthan, so much so that rocky and gravelly wastelands with 10 cm or less sediment cover and tall sand dunes became transformed into irrigated croplands. The change in source-wise irrigation is visible in Figure 3.9a. As open wells started drying up, and electricity and tubewell technology was highly subsidised, groundwater was increasingly sourced from tubewells. The rise of irrigation and associated inputs in Jodhpur district are shown in Figures 3.9b and 3.9c.

Figure 3.9a: Change in source-wise irrigation in Jodhpur district (1966-2007) (in '000 Ha)



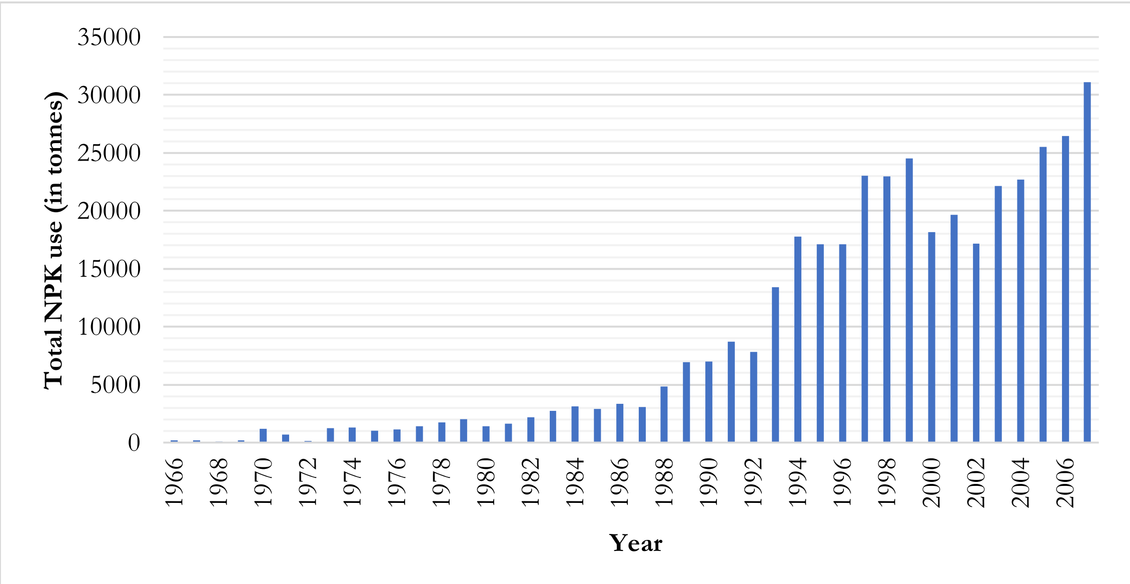
Source: Derived using data from NICRA (2014)

Figure 3.9b: Trend in area under irrigation in Jodhpur district (1966-2010) (in '000 Ha)



Source: Derived using data from NICRA (2014)

Figure 3.9c: Trend in total use of NPK* fertilizer in Jodhpur district (1966-2007) (in tonnes)



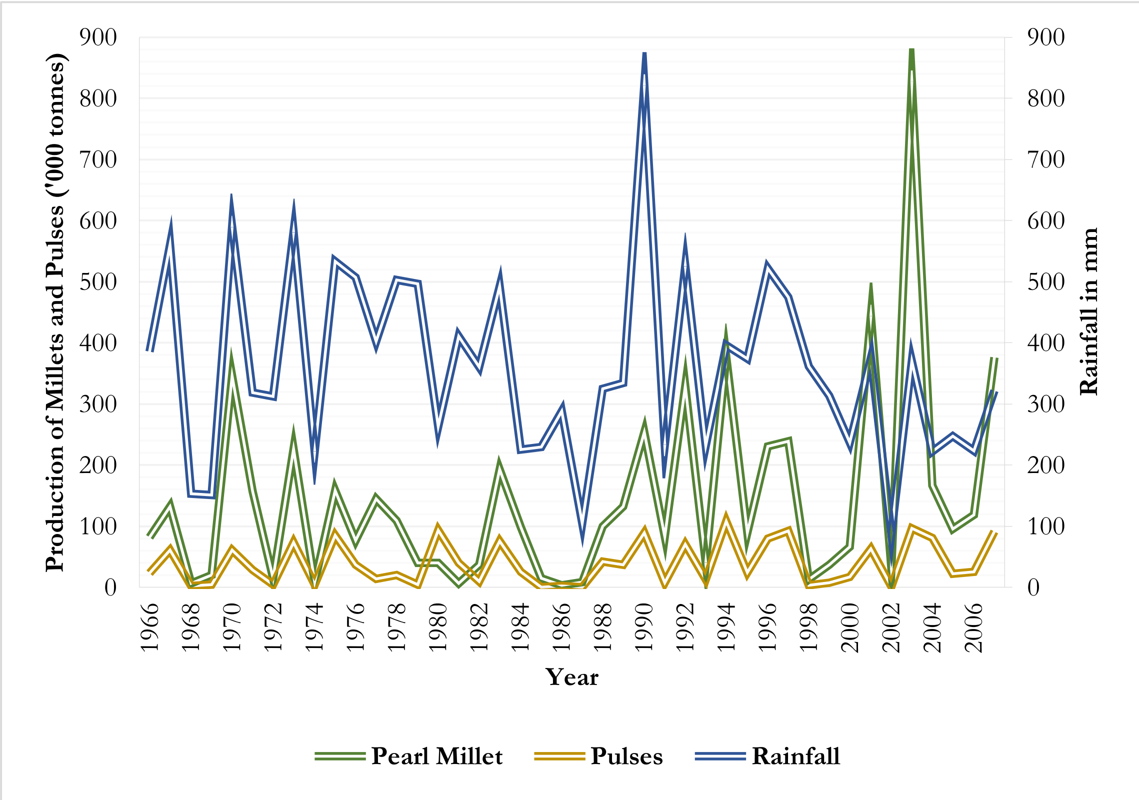
**NPK: Nitrogen, Phosphorous and Potassium; Source: Derived using data from NICRA (2014)*

In Jodhpur district, there are significant changes in land utilisation between 1966-67 and 2009-2010 (Figure 3.8). There has been a gradual increase in net sown area at the expense of land under fallow, with many farmers slowly abandoning the traditional practice of land fallowing[47].

High-input agriculture led to an increase in both area under cropping and yields of key crops (Swaminathan, 2017). While the focus of the Green Revolution was on improving crop productivity (per ha) of key cash crops, such as wheat, it also led to improvements in overall production and productivity of key staple crops of Jodhpur. However, in tracing yields of pearl millet and pulses, it is evident that variability in the production of these crucial staple crops remains high; there are now higher highs and lows, and crop yields are still heavily reliant on the monsoons (Figure 3.10).

[47] Area under fallow includes for current fallow and other longer fallows (as illustrated in Figure 3.11). See Appendix I for definitions of these terms.

Figure 3.10: Production of pearl millet and pulses with rainfall in Jodhpur district (1966-2007)



Source: Derived using data from IMD (2014) and NICRA (2014)

While the Green Revolution contributed to the development of agriculture by introducing irrigation in the water-scarce regions of western Rajasthan, debates have since focused on the impacts on growth, equity, and sustainability. Ninan and Chandrashekar (1993) presented five key issues brought on by the Green Revolution in the drylands of India:

(i) Variability of crop yields: While crop yields increased through the 1990s, variability of these yields also increased in comparison to earlier records. As illustrated in Figure 3.10, inter-annual variability of yields remains high and continues to be heavily contingent on rainfall. There are several years, such as the drought of 2002, where production was close to zero. Swaminathan (2017) showed that the productivity of key cash crops (e.g. wheat and rice) in Punjab - a state that was the focal point of the Green Revolution - had plateaued since 1996-97 through to 2007-08. Crop productivity in Jodhpur is analysed in Chapter Five.

(ii) Costs of cultivation: While the food grain output increased, so did the costs of cultivation due to the reliance on heavy input machinery.

(iii) Ecological degradation: The focus on intensification brought with it many ecological problems, including degradation of land resources.

(iv) Institutional barriers: Despite the scale of implementation of newer agricultural technologies, poor implementing institutions and economic constraints remain a critical stumbling block.

(v) Equity: Certain sections of society, regions (humid and sub-humid regions) and sectors have benefitted enormously from these changes while others showed limited growth and increasing inequities. For example, while areas such as Punjab benefitted, in the rural areas of Jodhpur inequalities were perpetuated.

Therefore, while the Green Revolution addressed some of Jodhpur's problems by providing greater access to groundwater for agriculture, it failed to address issues of equity and access. Further, the focus on irrigated cash crops at the expense of subsistence staple crops such as pearl millet, has had important consequences for food security, and will be explored in Chapters Five and Six. Importantly, in implementing the technologies of the Green Revolution, local knowledge was ignored, neglecting considerations of the socio-cultural context of the technological applications introduced (Reed & Stringer, 2016). This information is important as it places in context some of the key transformations that have brought about inequitable agricultural systems in Rajasthan that exist to this day.

While the previous two sections have traced the history of agriculture until the mid-2000s, the next section will present a discussion of agriculture and livelihoods in the present time.

3.4.3 Status of agriculture and livelihoods in the 21st century: current challenges and perspectives in Jodhpur

Despite the changes brought on by the Green Revolution, agriculture in the arid regions of Jodhpur continues to face challenges of highly variable crop yields, and increasingly scarce and degrading resources. A brief analysis of agriculture and livelihoods in present day Jodhpur is presented below.

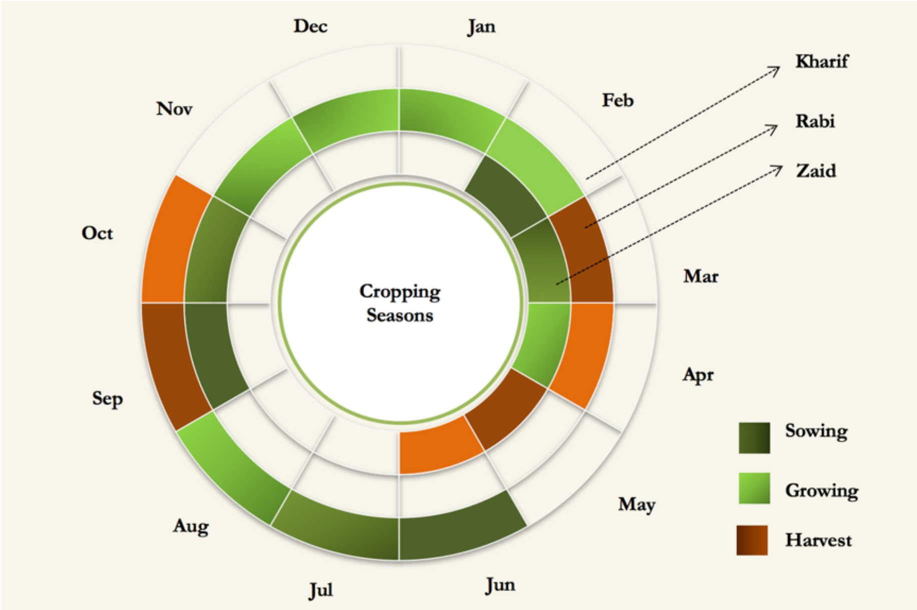
Agriculture: A majority of the rural population continue to live by traditional subsistence farming and pastoralism. A typical western Rajasthan family has between 6-8 members, engaged in rain-fed farming. The family will own around 3-4 ha of land containing randomly distributed trees of *P. cineraria*, *T. undulata, P. juliflora, Neem*, some shrubs and occasional grasses. They will also own 10-12 livestock, including cows, buffaloes, goats, sheep and camels, which feed on the trees and shrubs. The monsoon crops typically grown include, pearl millet (*bajra*), pulses such as moth bean and mung bean, sesame, and cluster bean (*guar*), often in mixed cropping, so that even when a moderate drought occurs, some crops will survive. Their food requirements are largely met through preparations made out of dairy, pearl millet, and chillies. The *P. cineraria* (*khejri*) tree is a key source of sustenance with the barks and beans used to make curry and the leaves used as livestock fodder (Picture 3.4) (Kar, 2014a).

Picture 3.4: Every year during September to November, the leaves, bark and beans of the *khejri* tree are removed and harvested for use as food, fuel, timber and fodder for the remainder of the year. Women typically work on this painstaking task of separation, as seen in this picture

Source: Author's own

On account of its aridity, cropping patterns are largely rain-fed, following a single cropping pattern during the monsoon. Only 15% of the net cultivated area is utilised for double/multiple cropping (CGWB, 2014). The main cropping season occurs between early June to early October and is known as *kharif* or monsoon crop. In areas where double-cropping is possible (largely due to groundwater irrigation), a second crop is grown from late September to early April called, *rabi* or winter crop. An additional third cropping cycle also occurs from late February to early June for certain specialised crops, such as cotton, called *zaid* or summer crop. A cropping cycle calendar is illustrated in Figure 3.11 below, with the outermost circle indicating *kharif*, second circle indicating *rabi* and innermost circle representing *zaid*.

Figure 3.11: Typical cropping cycle calendar for the study area in Jodhpur, Western Rajasthan



Source: Author's own

During *kharif*, largely subsistence crops such as, pearl millet (*bajra*), green gram (*mung*), moth bean (*moth*), cluster bean (*guar*), and sesame (*til*) are grown. In addition, castor is also sown in *kharif*, where irrigation is available. Key *rabi* crops grown include, wheat, cumin, rapeseed and mustard, *Psyllium* husk (*isabgol*), and vegetables such as carrot, radish, cauliflower, onion, and garlic. Cotton and a second wheat crop are typically grown during *zaid*. Information on current trends in productivity of these crops is included in Chapter Five.

An analysis of land change dynamics in Rajasthan, over a period of six years (2004-05 to 2009-10), demonstrates (Table 3.5) significant changes in terms of area under double crop at the cost of area under single crop (*kharif*) together with the loss of fallow land signifying increases in cropping intensity (Pathak, 2015).

Table 3.5: Change in area under different land use/cover categories (km²) in Rajasthan

Categories	2004-2005	2009-10	Difference
Kharif only	23,587	16,717	-6870
Rabi only	11,715	11,171	-543
Zaid crop	0	94	94
Double/triple crop	14,694	25,264	10570
Current fallow	60,845	59,510	-1334

Source: Adapted from Pathak (2015)

The average landholding size in Jodhpur district is around 3 ha, which in Rajasthan is classified as a semi-medium landholding. Landholding classifications in Rajasthan are included in Table 3.6; 55% of the total number of operational landholdings belong to small and marginal landholders (cultivating less than 2 ha), but they only operate 14% of the total operational land area. Large landholders (with more than 10 ha), constitute only 7% of total holdings but occupy a substantial proportion of 37% of total land area (GoI, 2016).

Table 3.6: Landholding classifications and pattern in Rajasthan (2005-06)

Size class	Total Holdings		Average size of holdings (Ha)
	Number	Area (Ha)	
Marginal (0-1 ha.)	2,073,099 (34)	1,016,368 (5)	0.49
Small (1-2 ha.)	1,321,126 (21)	1,895,062 (9)	1.43
Semi medium (2-4 ha.)	1,260,369 (20)	3,569,694 (17)	2.83
Medium (4-10 ha.)	1,103,263 (17)	6,796,010 (32)	6.16
Large (>10 ha)	428,625 (7)	7,661,858 (37)	17.88
Total	6,186,482 (100)	20,938,992 (100)	3.38

*Source: GoI (2016) *figures in parenthesis are percentages of the total*

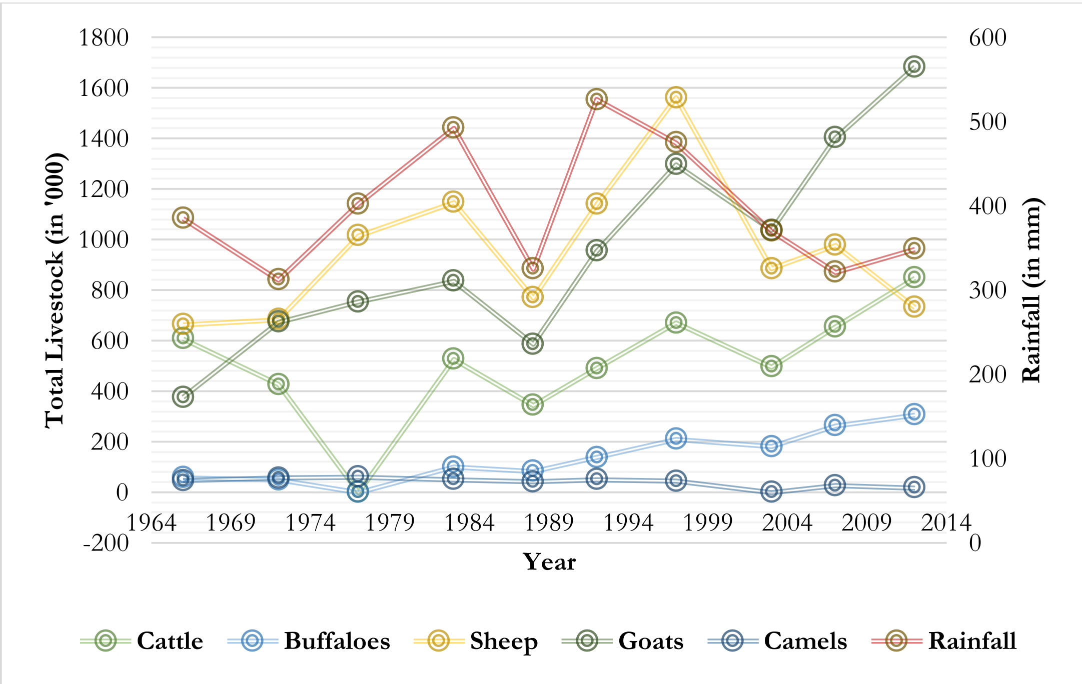
Livestock and semi-pastoralism: As agriculture is seasonal, semi-pastoralism is a key livelihood strategy for the remainder of the year. A mixture of animal types such as cattle, sheep, goats, and camels are reared to maintain an effective and balanced use of different types of grasses, shrubs, trees and leaves (Joshi et al., 2009). Sacred forests and pastures attached to deities are still maintained in some areas, known locally as *Orans* (community forests) and *Gochars* (community grazing lands). These have been in place for centuries, as a means to sustain livestock, now there are fewer *Orans* and *Gochars*. Where they exist, cutting of trees within these sacred areas is prohibited and the act is subjected to severe penalties (Gagné, 2013; Jodha, 1985). Cows and buffaloes claim high value, and are given as dowry[48] during weddings; camels, the mainstay for transportation, have slowly lost their importance as road transport facilities have become developed. Sheep offer a key source of income; indeed, the *Raika* nomads of western Rajasthan were said to produce two-thirds of India's wool at one time (Robbins, 1998). The importance of goats, known as the poor man's cow or the 'fridge of the desert', lie in their ability to yield milk whenever required. Typically, larger herds of livestock are maintained due to high mortality rates of animals in the desert (Louhaichi et al., 2014). According to a common folk saying, "during fodder scarcity the camel will leave only *Callotropis*, while the goat will leave only pebbles" – which imply that the goat can survive on the scantiest vegetation, while providing manure for the soil" (Malhotra & Mann 1982: 309). With only around 5% of land under permanent pasture, animals subsist on poor quality weeds,

[48] The dowry system is common in India and omnipresent in Rajasthan. In fixing a marriage, a certain amount of property, money or livestock is given by a bride's family to the groom's family. The more 'worthy' the groom is, or less 'worthy' a bride is (in terms of caste, economic status, physical beauty, and location), the more resources/money demanded by the groom's family. In Rajasthan, livestock is the most common dowry exchanged, rather than property.

crop residues or are stall-fed with increasingly expensive fodder procured from the market or from within the village.

Figure 3.12 shows that, in the mid-1970s and 1980s, during consecutive years of drought, the population of cows and buffaloes decreased, while the population of sheep and/or goats rose. More recently, with further deterioration of grazing areas, a decline in the sheep population is evident since they require more effort to graze as herders travel longer distances in search of fodder (Picture 3.5). Similarly, camels were the main means of transportation 20-30 years ago (Picture 3.6), but the camel population has declined in recent years. This has led to an increased preference for cattle and buffaloes, which can be stall-fed.

Figure 3.12: Trend in livestock ownership in Jodhpur (1965-2015)



Source: Derived using data from IMD (2014), GoR (2015)

Picture 3.5: A shepherd herding sheep and goats returning from a long day's grazing. The lack of grazing lands surrounding villages mean often herders have to walk long distances, leaving before sunrise and returning before dusk.

Source: Author's own

Picture 3.6: Camels a main-stay in every household in the area for transportation about 20 years ago, are now a rarer sight. The advent of roads has made them less valuable. Some farmers in remote locations still use them for transporting crops and water

Source: Author's own

This section has described the key trends and transformations surrounding agriculture and livelihoods in rural Jodhpur. It is clear that these developments in looking to achieve goals of self-sufficiency and reduction in rural poverty have altered the agrarian landscapes of the region. As in the rest of India, inequity in growth and development has intensified, with lopsided benefits of the 'agricultural revolution', increasing the vulnerability of large sections of Jodhpur's rural population. For instance, despite these transformations, communities and landscapes in the region remain highly exposed to climate variability and change (due to their location and dependence on agriculture), they remain highly sensitive (due to continued socio-political marginality) to any perturbations and while traditional adaptive capacities have kept them resilient, newer social, political and climatic changes have left them with large uncertainties in adapting to change.

3.5 Vulnerability in India's arid drylands

Vulnerability research in India has largely followed an 'outcome' approach, focussing on vulnerability of agriculture and forests to the impacts of climate change (Aggarwal, 2009; Gerlitz et al., 2016; O'Brien et al., 2004b; Singh & Nair, 2014; Soora et al., 2013). An important national-level assessment of vulnerability of agriculture to climate change in India's 676 districts, was conducted by CRIDA (2013), using largely biophysical data. Jodhpur district was estimated to be the third most vulnerable district to climate change in India (Rao et al., 2016). The top five most vulnerable districts are all from Rajasthan, as shown in Table 3.7.

Table 3.7: Vulnerability ranking as measured by CRIDA

District	Rank Based on			
	Exposure	Sensitivity	Adaptive Capacity	Overall Vulnerability
Barmer	169	16	550	1
Jaisalmer	68	24	527	2
Jodhpur	**134**	**8**	**474**	**3**
Bikaner	166	23	508	4
Nagaur	311	20	489	5

Source: Rao et. al (2016)

Key indicators selected for assessment are included below (Chapter Two defines these concepts):

- Exposure: long-term decreases in July rainfall, number of rainy days, maximum and minimum temperature;
- Sensitivity: area prone to flood or drought incidence as a percent of TGA, available water holding capacity of the soil, net sown area as a percent of TGA; and

- Adaptive capacity: percent of rural poor, percent of literacy, net irrigated area, fertilizer consumption per hectare.

More recently, following the lead of the Government of India, who have emphasised the need for bottom-up planning, there has been interest in community vulnerability assessments (e.g. Rajesh et al. 2014; Esteves et al. 2016; Gerlitz et al. 2016). However, these shifts in knowledge and understanding of vulnerability have not yet transferred to India's arid drylands. There has been relatively little academic attention to the assessment of vulnerability in India's arid drylands. A study by Birkenholtz (2012) is one of the few exceptions.

Birkenholtz (2012) in a largely conceptual paper argues for the use of network political ecology in understanding the vulnerability to climate change. The author also draws upon ongoing research with groundwater-dependent farmers in two districts of Western Rajasthan. Using only social parameters, he reports that current approaches to vulnerability cannot adequately explain the differences in vulnerability and its variance between communities. He calls for future vulnerability research to build a middle-range theory that focuses on differing time-space scales while providing a more nuanced understanding of networks and connections between local stakeholders (ibid.). The findings also highlight the need for research to find ways to incorporate ecological conditions such as soil and groundwater into qualitative research.

As with global vulnerability research (Chapter Two), vulnerability to climate change in India's key sectors continues to be widely assessed. However, there remains a need to understand if these broader-scale methodologies and findings translate to the more unstable and complex arid regions of India. Methodologies are needed that in assessing vulnerability, also recognise the resilience of arid communities and landscapes.

If solutions are to be found that seek to reduce land, water, and biomass depletion while reducing the overall risks faced by arid zone communities, a first step is to gain a better understanding of the inherent socio-ecological system complexities. These key gaps and challenges are drawn upon in developing a conceptual and methodological framework of assessment for this study.

3.6. Conclusions

Studies from the 1970s exemplify the people of Western Rajasthan as practitioners of land and water conservation and experts of sustenance, who are well able to survive the harsh conditions presented by their environments. Over time, these same practices have become regarded as outdated and in need of transformation. This perception has clear implications for the research questions posed in this thesis. The question of how a society that was focused on conserving water and safeguarding their land systems, became one where both land and water resources are severely degraded, will be addressed through this thesis.

Similar to the challenges identified in Chapter Two, there remains a need for drylands research in India to find ways to better integrate the social parameters of degradation; in particular a shift is needed from regional to local scale assessments. These key gaps and challenges are drawn upon in Chapter Four in developing a conceptual and methodological framework of assessment for this study.

Despite its intriguing socio-cultural and agrarian history and exciting contemporary developments, the rural agro-ecosystems of Jodhpur have received relatively little academic attention both in India and in global drylands literature. Overall there is a severe lack of focus on understanding both the constraints and resilient attributes of agriculture and livelihoods in these arid regions. This thesis therefore contributes to this area of literature through developing a conceptual framework that is built on information derived from an understanding gained through tracing the histories of land and society in rural Jodhpur, and from multiple fields of literature (Chapter Two). The next chapter provides details on the conceptual and methodological framework of assessment.

4. Research Methodology

The methodology utilised to conceptualise, design, collect, and analyse data is presented in this chapter. The significance of incorporating 'vulnerability' into research and adaptation planning in drylands prone to degradation, has been highlighted in earlier chapters. To this end, a framework is conceptualised and empirically developed for assessing the vulnerability of dryland agro-ecosystems to multiple stressors in the arid district of Jodhpur, Rajasthan.

The research followed a non-linear and iterative approach, using mixed methods that combine elements of both qualitative and quantitative research. This resonates with the position of most dryland scholars who maintain that a richer understanding of dryland landscapes and societies can be achieved using approaches that draw upon mixed methods from various disciplines. Consequently, literature on drylands, vulnerability, sustainable livelihoods, and political ecology are used to develop the concepts and methods used in this research. Further, the framework is developed in keeping with the socio-ecological context of the study location of Jodhpur, Rajasthan. The field study was conducted during 2015 and 2016 in Jodhpur and its rural areas to gain better insights and knowledge into the study location and collect data for the research.

The chapter is structured as follows:

- Section 4.1 introduces the purpose and scope of this research, and highlights the key research questions;
- Section 4.2 presents the conceptual framework of the analysis and the key epistemological positions taken in designing the research;
- Section 4.3 highlights the data and methods used to operationalise the assessment;
- Section 4.4 provides information on research design, introducing the value in using a case study approach, and the selection of two clusters in Shergarh and Osian as the primary blocks of interest for the empirical field work;
- Section 4.5 discusses the techniques used for collecting both primary and secondary data;
- Section 4.6 presents the strategy followed in the analysis of data and its presentation in this thesis;
- Section 4.7 highlights some of the key difficulties and challenges encountered during the field study and analysis; and
- The final section 4.8 summarises and concludes this chapter.

4.1 Research purpose and scope

This research rests on the understanding that dryland degradation is a complex, non-linear, multi-disciplinary concept, arising from the interaction between climate, ecosystems, and social systems within inherently dynamic environments. The research tests the hypothesis that dryland degradation can be better understood through the lens of the human-environmental vulnerability within which it is now embedded. This is critical to not only understand the 'drivers' of land degradation but also its implications for sustained food production and livelihoods.

The methodology is developed using a conceptual framework that is underlined by 'vulnerability' as a concept that is embedded within a given dryland agro-ecosystem[49]. Discussions in the previous two chapters have highlighted how the limitations in recognising the multiple and interlinked dimensions of dryland degradation and their interactions across various scales have led to misconceptions and controversies in drylands research. Through its interdisciplinary concepts, and foundation in theories of sustainability and livelihoods, it is likely that an assessment of vulnerability will provide answers to the way socio-ecological systems function in drylands.

With a focus on dryland agro-ecosystems in Jodhpur, the research identifies ways through which status and the use of land, water, and biomass resources intersect with vulnerability to land degradation and climate risks. The conceptual and methodological framework applied in this research incorporates elements of both conservation/restoration of degrading land resources and adaptability of the socio-ecological system to adjust to climate variability and change. This is critical to not only understand the 'drivers' of dryland degradation, but also to appreciate the implications for sustained food production and livelihoods.

4.1.1 Research questions

As set out in Chapter One, research is undertaken to address three main overarching research questions (RQ):

- **RQ1:** How do dryland degradation and climate risks impact on agriculture and livelihoods in Jodhpur?
- **RQ2:** What are the key elements to be included in a framework of drylands vulnerability, that helps gain insights into the drivers of vulnerability and their interactions with the drivers of land use and land degradation?

[49] An agro-ecosystem is defined as an ecosystem under agricultural management, connected to other ecosystems (OECD, 2001)

RQ3: How can vulnerability be incorporated into broader land management and adaptation planning so as to sustain dryland agro-ecosystems through reclaiming land resources while enhancing resilience to the effects of climate variability and change?

These three questions will be addressed through the following research objectives, that:

- Examine the state and trends in dryland degradation in Jodhpur district, Rajasthan;
- Understand the interdependencies and feedback effects between land use, land degradation, and climate variability;
- Develop a framework for vulnerability assessment, keeping in the mind the unique and stratified nature of Jodhpurs' drylands;
- Identify households, villages, and clusters of villages most vulnerable to the combined effects of dryland degradation and climate variability and establish what makes them vulnerable;
- Understand the implications of this vulnerability for land use and land degradation through an investigation of the functional relationships between the status and dynamics of land, water, biomass use and vulnerability; and
- Suggest context-specific recommendations for incorporating adaptation with the framework of sustainable dryland management.

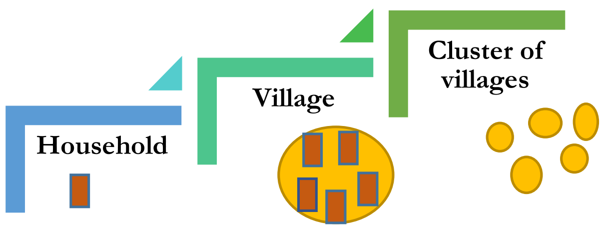
4.1.2 Scope of the research

In addressing the potentially broad field of study identified, the scope of the research is controlled through the use of a local level, participatory approach. Yin (2009) and Stake (1995) state that placing boundaries within a case can help prevent common pitfalls of losing focus by examining too many elements. Central elements of the research scope are as follows:

Focus on dryland agro-ecosystems in two selected village clusters of Jodhpur, Rajasthan: The research focuses on dryland agro-ecosystems through the study of two clusters of villages in the Jodhpur district of Rajasthan. The rationale for selection of these clusters is provided in Section 4.4 of this chapter. Only issues relevant to this local area, as determined through the field study and secondary data are studied.

Local level, multi-scale approach (Figure 4.1): In Chapter Two (Section 2.5.2) issues of scale and their significance for coupled socio-ecological systems research were highlighted. The processes surrounding both dryland degradation and vulnerability can occur on multiple spatial and temporal scales. In developing the research methodology, the research incorporated three different scales: the household, the village, and a cluster of villages. The household is chosen as the basic unit of analysis, where a household is defined as those living within the same compound, using common resources and sharing a common kitchen[50]. This is followed by the village-level, where a 'village' is an administrative unit with a boundary including all the land, water and livestock resources and humans residing within it. Finally, the cluster-level, includes a group of villages, located near to one another, with similar socio-ecological systems (Section 4.4 describes the composition of the two clusters). District-level data is introduced where secondary data and information are available. In addition, broader scales such as region, state, national and global are considered only where they are relevant to a particular household, village, cluster or district. For instance, only climate patterns that are relevant and impact on a respondent's agriculture or livelihood activities are considered. Similarly, broader policies and programmes put forth by the central and state governments are considered only if they are applicable to the communities in question.

Figure 4.1: Multi-scale approach to analysis



This level of analysis will overcome common criticisms in this line of research, such as the inability of studies to bridge the gap between local experience and scientific evidence. Additionally, the multi-scale approach will help ensure that the study and results are robust.

Land degradation as an integrated concept: Studies generally consider land as a separate entity from water and biomass-based resources. Land, water and biomass are however inter-linked in a typical 'village ecosystem', and a failure in one aspect will lead to knock-on effects on the others. In the present study, 'land' includes all land categories in a village ecosystem such as cropland, forest land, grazing land; 'water' includes rainfall, ground water and surface water resources of a village ecosystem; 'biomass' includes food grains, fodder, fuelwood, biofuel, timber and fibre.

[50] A household is defined by the Indian National Census as, 'a group of persons who normally live together and take their meals from a common kitchen unless the exigencies of work prevent any of them from doing so' (Census, 2011). The emphasis on common kitchen was used in this study, alongside taking into consideration people living within the same compound and contributing to a particular household's livelihood.

The following sections outline the conceptual framework including the key epistemological choices made, followed by the methodological approaches utilised to guide assessments of these concepts.

4.2 Conceptual framework of analysis: Epistemological positions

The conceptual framework of analysis draws upon the key research gaps in dryland literature (Chapter Two); it is tailored specifically to the case study context of Jodhpur, Rajasthan (Chapter Three). Five cornerstones of the conceptual framework of analysis are presented below and these build on research conducted in political ecology, vulnerability, and wider dryland degradation research. The constituents of this paradigm are not all novel. However, taken together the framework will shed new light on the problems of dryland degradation. The key principles of the framework are summarised in Table 4.1 and these are clarified throughout the rest of this chapter. Using these principles, a conceptual framework of analysis is developed as illustrated in Figure 4.2.

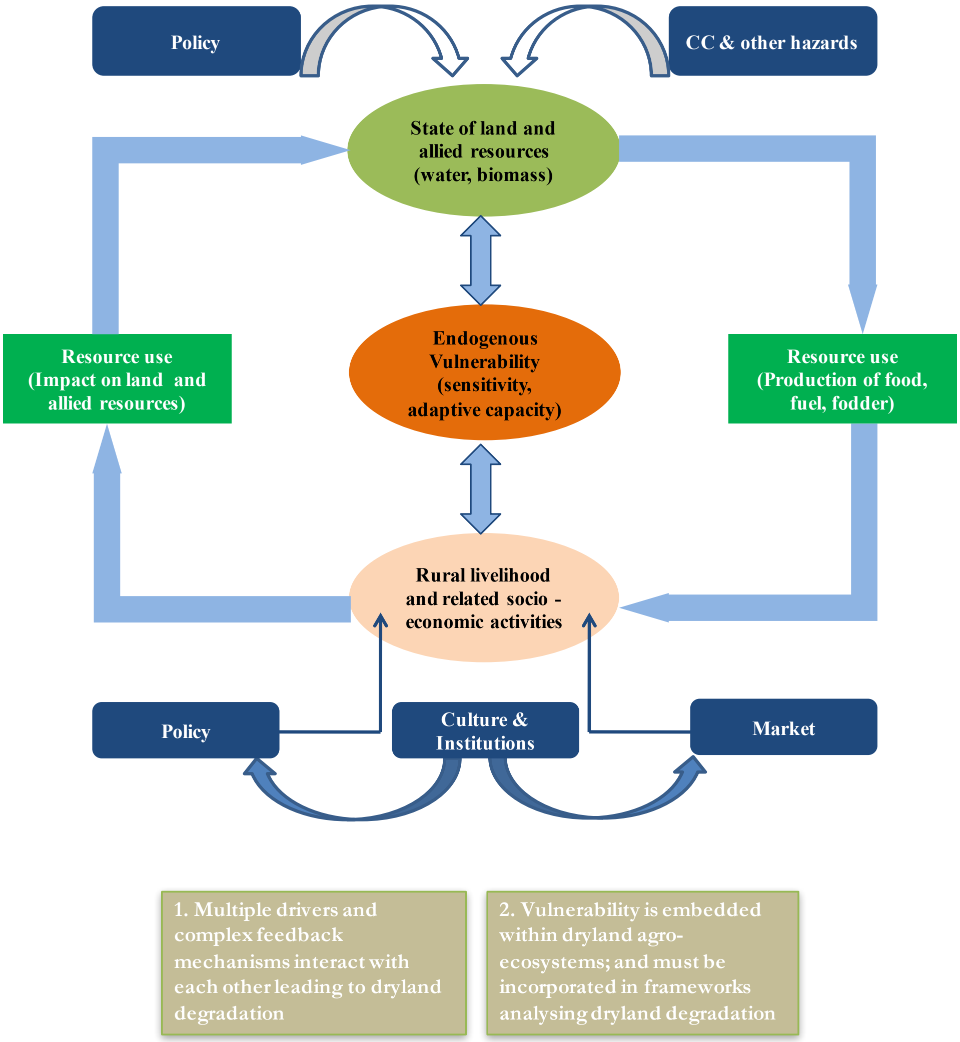
Table 4.1: The five cornerstones of the conceptual framework of analysis

Cornerstones	Principles of assessment	Assessment approach
Principle I	Human-environment relationships in drylands are dynamic, systemic and non-hierarchical	Drylands are approached as a dynamic socio-ecological system
Principle II	Context is significant in dryland studies	Local-level study involving two distinct dryland agro-ecosystems in Rajasthan
Principle III	Complex linkages among attributes and mechanisms	Field-driven study investigating the open-ended plurality of perspectives and experiences to help draw out the links between attributes and mechanisms
Principle IV	Significance of issues of scale	Multi-scale analysis at household, cluster and village level. Broader-scale policies, institutions and markets are also incorporated. The temporal scale is addressed through an examination of trends in climate and land use; and through an exploration of participant histories
Principle V	Vulnerability is embedded within dryland agro-ecosystems	Study of 'endogenous' vulnerability in drylands as central to the functioning of dryland agro-ecosystems

In the conceptual framework presented in Figure 4.2, 'state of land and allied resources' (water and biomass) represents the biophysical system state, and 'rural livelihoods' represents the social system state. It is difficult to design an assessment of all the dynamic socio-ecological components that make up a particular dryland agro-ecosystem. The concept of vulnerability, in light of system complexity, will therefore act as a clearly defined and integrating concept (Whitfield and Reed, 2012), against which socio-ecological system change can be monitored.

Vulnerability is therefore conceived of as a human-centric, intrinsic part of the socio-ecological system upon which multiple stressors can and will impact.

Figure 4.2: Conceptual framework of analysis: showing the varying socio-ecological components of a dryland agro-ecosystem, centred on vulnerability embedded within the system and directly impacting on resources and livelihoods



Source: Author's own

Through a literature review, four elements became apparent: (i) the focus on land degradation as a social challenge, as taken from the literature on political ecology (Blaikie & Brookfield, 1987; Jones, 2008); (ii) the use of vulnerability as an endogenous concept taken from recent vulnerability literature (Hesse et al., 2013; IPCC, 2014; Salvati & Zitti, 2009; Singh et al., 2016); (iii) the importance of local knowledge and perceptions, proposed by more recent critiques of drylands research (Hesse et al., 2013; Reed & Stringer, 2015; Tarrasón et al., 2016; Whitfield et al., 2011); (iv) the need for mixed methods research, focussing on data triangulation, suggested by critiques pertaining to drylands research (Reed & Stringer, 2016; Singh et al., 2016;

Zampaligré et al., 2014). All four positions relate closely to each other and are discussed in detail in the following sections.

4.2.1 Land degradation conceptualised as a social challenge

While acknowledging the varying definitions and associated frameworks on dryland degradation, in the context of this populated study area, this research focusses on the concept of land degradation as introduced by Blaikie and Brookfield (1987). The authors state that land degradation is by definition a social challenge. While purely environmental processes such as erosion continue to occur with or without human interference, for these processes to be described as 'degradation' signifies that the reference is to some use-value denoted to the land. A 'use-value' is an essentially social criterion (ibid.).

This conceptualisation has been used in the Millennium Ecosystem Assessment (Safriel & Adeel, 2005) and by many dryland researchers (Geest & Dietz, 2004; Jones, 2008; Reed & Stringer, 2015; Reynolds et al., 2007; Warren, 2002). It is important to note that this definition is used here purely in the context of the drylands of Jodhpur, Rajasthan. As discussed in Chapter Three, the areas considered for this study are examples of some of the most populated arid zones in the world, where nature and society have clearly co-evolved. The validity of this conceptualisation in broader global drylands is beyond the scope of this thesis, albeit briefly discussed in Chapter Eight.

4.2.2 Vulnerability as an endogenous concept

Vulnerability in this research is assessed as an endogenous concept, focussing on system sensitivity (of both land and society) and (lack of) adaptive capacity. Using vulnerability to understand land degradation will aid both the identification of systems or households that are at risk, and in understanding why they are at risk (Turner et al., 2003b).

The terminology used in this thesis is thus 'endogenous vulnerability' - a term first used by Seitz (2011). It refers to vulnerability as a concept that is inherent to or embedded within a given dryland agro-ecosystem and is in line with a 'starting-point', 'contextual' or 'bottom-up' vulnerability as used by the IPCC AR5 (IPCC, 2014). This approach provides assurance that potential adaptation strategies are linked with multiple transformations and shocks, making it more about the endogenous factors that are responsible for 'vulnerability to change', where climate variability and change are only one part of the many transformations affecting a system (O'Brien et al., 2007).

4.2.3 The role of local knowledge

Despite widespread acknowledgement of the need to focus on local perceptions of dryland degradation, the rationales and aspirations of resident populations remain neglected in global drylands research (Dougill et al., 2010; Twyman et al., 2011). There is growing recognition of the value of research approaches that allow "people to explore problems in their own words" (Reynolds, 2007: 850). A plurality of voices can inform the rather detached concepts that are used to describe system dynamics. Critics often argue that incorporating local knowledge can compromise the rigour of the analysis (Abbot & Guijt, 1998). For instance, perceptions are a range of judgements, beliefs and attitudes, which can be dynamic and can be skewed by experience, memory, and expectations (Slegers, 2008). Adequate triangulation can help overcome some of these concerns. Further, many dryland studies including Stringer and Reed (2007), Tschakert (2007), Van Aalst et al. (2008) report significant overlaps between the knowledge of 'experts' and locals.

Importantly, care must be taken to avoid tokenism in the incorporation of local knowledge. Research generally presents local and scientific knowledge together in a way where knowledge from 'experts' is prioritised and often speaks more powerfully to the reader and policymaker (Whitfield et al., 2011). In placing the land manager at the centre, this thesis re-defines the 'experts' as the local communities; their observations are in essence undocumented science, developed through personal experiences and observations carried forward by generations who have lived off the land. Reed and Stringer (2016: 44) call this a "post-modern view of knowledge", where informal and tacit knowledge is given due weight.

4.2.4 The use of mixed methods

There is much debate in socio-ecological systems research on the benefits and limitations of both qualitative and quantitative research (Alessa et al., 2016). These discussions have increasingly given way to an acceptance of mixed methods research (Ostrom, 2009). This echoes current discussions in drylands research (Bisaro et al., 2014; Twyman et al., 2011). The research questions and real-world challenges presented by them requires a methodology capable of crossing boundaries set by purer conceptualisations of land and sustainable development (Reynolds, 2007). The research therefore uses mixed methods, through creating a number of dynamic structures emerging from secondary data and then working within those structures to advance theories of dryland degradation and vulnerability using primary data, including the perceptions of local communities. It is expected that adequately triangulating both primary and secondary data will overcome some of the common limitations of both approaches.

Having discussed the key concepts relevant to the methods, the following section will focus on how these concepts are operationalised, in particular how vulnerability, conceived of as an integrating concept, is analysed using both quantitative and qualitative methods.

4.3 Methodological framework: Developing an 'agriculture and livelihoods vulnerability framework' for dryland agro-ecosystems

In practical terms, one of the main contributions of this research is the development of an actionable vulnerability framework that is replicable while staying relevant to the communities. This is a challenging task and the remainder of this section will focus on the broad approach followed in developing the vulnerability framework. To meet the aims of this study, two assessment methodologies are developed to overcome the common difficulties of the practical ineffectiveness of vulnerability assessments. Community perspectives are incorporated within both these assessments.

1. A vulnerability index method – 'Agriculture and Livelihoods Vulnerability Index (AgLiVI)' – to assess the key drivers of vulnerability across the scales selected for this study. This index-based assessment uses criteria and indicators[51] based on IPCC (2014) concepts of sensitivity and adaptive capacity (see Section 2.4).
2. A qualitative narrative-driven approach to enhance knowledge of the key drivers of drylands vulnerability.

A combination of these two methods helps utilise the strengths of both approaches to identify the practical drivers of vulnerability. Only a broad overview of the steps followed in developing the vulnerability framework are highlighted here and details of the particular indicators selected and the rationale for their selection will be provided in Chapter Six, which includes a detailed analysis of vulnerability. The steps involved in a typical vulnerability index assessment are illustrated in Figure 4.3. Each of these steps are now discussed.

Figure 4.3: Typical steps followed in the formulation of a vulnerability index

Source: Author's own

4.3.1 Identification of sector and scale

As discussed in Chapter Two and Chapter Three, several authors have highlighted the need for an investigative approach to vulnerability that extends to multiple scales within an affected

[51] Some studies also use primary and secondary indicators in assessments of vulnerability.

region (Birkenholtz, 2012; Claessens et al., 2012; Esteves et al., 2016a). The vulnerability analysis in this study thus follows a multi-scale approach; the household, village, and cluster of villages as illustrated in Figure 4.1. Further, the use of two distinctive clusters helps gather evidence on vulnerability within the diverse social groups and biophysical systems that co-exist within the same region.

4.3.2 Selection of criteria and indicators

Since vulnerability is not a directly observable parameter (Hinkel, 2011; Tonmoy et al., 2014), interpretations and measurements are conducted through proxy indicators and/or characteristics of vulnerability. There is no universally accepted list of indicators or methods to combine indicators in vulnerability assessments (Rajesh et al., 2014). Careful consideration in the selection and inclusion of indicators is recommended as assessments can vary based on which indicators are chosen (biophysical/social) and how many indicators are chosen (too few/too many). It is possible to have a direct set of indicators or a set of primary indicators. Each or some of these primary indicators can include a set of sub-indicators. The primary indicators are also called criteria (Sharma et al., 2013).

In this assessment, the term 'criteria' is used to describe the primary indicators of assessment. At the outset, broader criteria were first established (e.g. agricultural diversification, social dynamics) and within these broad criteria, indicators were selected that helped define the criteria (e.g. number of crops, number of household members). The selection of criteria and indicators was done using a combination of previous vulnerability assessments (Appendix II), which were then narrowed down during the field study. It was critical to select criteria and indicators of relevance to the political, social, economic, and ecological context of the study area. A recurrent critique of indicators is the imposition of outsider views and arbitrary outlooks, in terms of choosing which data to collect and how to analyse the data (Scoones, 2015). The selection of indicators from participatory processes helps to resolve this dilemma to an extent. Nevertheless, the selection remains subject to researcher-subject power relations and subsequent biases (McDowell et al., 2016; Sherman et al., 2012).

4.3.3 Quantification and normalisation of indicators

The focus of a vulnerability index is on articulating a quantitative function that can be used to reliably link system attributes (i.e. socio-economic or agriculture-based) to vulnerability outcomes such as yield decline, loss in land value or economic returns, or a decline in resource quality (Esteves et al., 2014). Data from various indicators come in different units and scales; these values must be normalised before combining them into an index. Based on the functional relationship of a given indicator to any vulnerability outcome, the indicator is typically normalised using one of these two formulae:

- If an indicator has a negative (-) functional relationship, then vulnerability increases with decrease in the value of the indicator; the lower the value of the indicator the greater is the vulnerability.
- Conversely, if an indicator has a positive (+) functional relationship, then vulnerability increases with increase in the value of the indicator.

In this study, the following formulae were used to normalise the different indicators depending on the relationship of the indicator with the dimension.

Formula (i) is applied when the indicator is positively related to vulnerability

$$Y_{ij} = X_{ij} - Min\{X_{ij}\} / Max\{X_{ij}\} - Min\{X_{ij}\}. \qquad (i)$$

$$when,\ X_{ij} = 0,\ Y_{ij} = 0$$

Formula (ii) is applied when the indicator is negatively related to vulnerability

$$Y_{ij} = Max\{X_{ij}\} - X_{ij} / Max\{X_{ij}\} - Min\{X_{ij}\} \qquad (ii)$$

$$when,\ X_{ij} = 0,\ Y_{ij} = 0$$

where Y_{ij} is the normalised value of the indicator *i*, corresponding to the household *j*, X_{ij} the actual value of the indicator *i*, corresponding to the household *j*, Max$\{X_{ij}\}$ the maximum value of indicator *i*, among the selected respondents per cluster and Min$\{X_{ij}\}$ is the minimum value of indicator *i*, among the selected respondents per cluster.

The process of construction of the vulnerability index involved normalising all the indicators and then averaging the resultant normalised values. Normalised values of indicators lie between zero and one; an indicator with a value closer to one has a greater influence on vulnerability and an indicator with a value closer to zero has the least influence on vulnerability. This methodology has been used in the computation of the Human Development Index[52] (UNDP 1999, 2006). It has also been widely used in vulnerability assessments in India, including by Rao et al. (2016) in an analysis of the vulnerability of Indian agriculture to climate change for the Government of India's ICAR and others (Balica et al., 2012; Brenkert & Malone, 2005; Esteves et al., 2016a).

4.3.4 Developing weights for criteria and indicators

Weighting highlights the relative importance of different indicators (Tate, 2012). The weighting parameter includes options of equal and expert weights (Beccari, 2016). In this research, relative weights were sought for the primary vulnerability criteria by the respondents through

[52] Although, in the Human Development Index (HDI), all components are positively related to the HDI.

two focus groups. After an explanation of each criterion chosen for the assessment, the two focus groups were asked to rank them in order of importance[53]. Weights were then given to primary criteria on a scale of 0 to 1, such that the total of all the weights equal 1. Assigned weights are provided in Chapter Six (Table 6.2). For hierarchical models using differential weights, a decision needs to be made on whether the weights are applied at the criterion or sub-index level or both. For this study, weights were given to the primary criteria, and equal weights were assigned to indicators within each criterion.

$$W_{Total} = W_1 + W_2 + W_3 + \cdots + W_n = 1$$

Where, W_1, W_2, W_3,….., W_n are the individual weights assigned that correspond to the criteria (1,2,3…n) selected, whose total = 1.

Previous work has suggested that equal weights at the sub-index level are more likely to be beneficial unless there is justification for doing otherwise (Villa & McLeod, 2002). Tate (2012) opines that equal weights are used ubiquitously due to the scarcity of alternatives. In addition, stakeholders may face difficulties in comprehending a large number of indicators and providing relative weights to all these indicators. In this research, equal weights were assigned at the sub-index level and this will be discussed further in Chapter Six.

4.3.5 Aggregating the vulnerability index

To calculate the vulnerability index, the final weight of each indicator was multiplied by its normalised value and aggregated for all the indicators to obtain the Agriculture and Livelihoods Vulnerability Index (AgLiVI) value for each household, using the given formula.

$$AgLiVI_j = \sum_{i}^{n} W_i * Y_{ij}$$

The value of each household was then aggregated for the village and finally for each cluster.

4.3.6 Enhancing the vulnerability index with community knowledge

Having developed a structured and quantitative vulnerability index, qualitative investigations of vulnerability were conducted to gain an in-depth and grounded perspective on the drivers of vulnerability identified through the index. Qualitative vulnerability was analysed through the prism of local politics, reliability of access, sustainability of their existing adaptive capacities, and community-based interpretations of socio-ecological thresholds (Chapter Six). As discussed in Chapter Two, there remains uncertainty regarding the utilitarian value of a

[53] See section 4.5.4 for details of the weighting exercise. The weights provided by the two focus groups were averaged for the final weight to be used in the index.

vulnerability index for drylands. It was thus important to understand if criticisms levelled against quantitative index-based assessments of vulnerability were well-placed. In the context of this research, close interactions with the communities and observations of their interactions with their environments, gained through the field research, allowed for these questions to be answered. The outputs of the vulnerability analysis therefore identified:

(i) Who is vulnerable?
(ii) Why are they vulnerable?
(iii) What are the drivers of vulnerability?
(iv) What are they doing to mitigate the factors driving their vulnerability?

Overall in developing a quantitative index-based approach and by extending it to include qualitative evidence, the study required a variety of data collection and analysis methods, which are discussed in the following sections.

4.4 Designing the field research

The research utilised a case study approach and within this broader approach used embedded cases of two different clusters in Jodhpur district, Rajasthan. The following sections describe the rationale behind the selection of the embedded case study approach in Jodhpur, India and highlight the key sampling strategies followed in designing this mixed methods study.

4.4.1 Why a case study?

Case studies investigate contemporary phenomenon within a real-life context in order to explore complex linkages (Yin, 2003). In particular, they support the deconstruction and the subsequent reconstruction of various phenomena (Baxter & Jack, 2008). In this research, a case study design was chosen to answer research questions that arose out of uncertainty about the relevance and availability of information from Indian and regional data sources. Further, the research required investigation into the significance of land degradation in shaping social and ecological landscapes in the region. A case study design generates situated knowledge, and helped to illuminate questions of 'who', 'what', 'how' and 'why' (Yin, 2009). As Adger et al (2005) suggest, a case study approach is most useful if the research seeks to come up with actionable information. This resonates with information presented in Chapter Three, which highlighted the absence of such diagnostic research in India's arid drylands, which has led to generic management strategies for differing agro-ecosystems. For instance, there are similar land use policies for the fertile landscapes of eastern Rajasthan and the arid landscapes in western Rajasthan.

4.4.2 Selection of location and familiarisation: Why Jodhpur?

The district of Jodhpur was selected for the field research and offers an ideal case for this research for three key reasons.

(i) Jodhpur is located in the arid west of Rajasthan and represents many of the key challenges highlighted in broader drylands literature. As discussed in Chapter Three, the district faces low and variable rainfall patterns and high summer temperatures; secondary data shows significant resource degradation and; societies and cultures that are marginalised from the larger development processes in India.

(ii) Data availability and the logistics of access to rural communities was easier due to the presence of the only arid zone research establishment in India, the Central Arid Zone Research Institute (CAZRI)[54], which houses a repository of information on drylands in India. CAZRI's support also simplified the selection of the clusters, villages, and households.

(iii) There are very few peer-reviewed publications offering insights into the distinctive livelihoods of those that live in this area.

4.4.3 Location scoping, pilot study and sampling strategy

After the district of Jodhpur was finalised, a pilot study was conducted during March-April 2015. The aim of the pilot study was to gain familiarity with the region, develop relationships with local stakeholders and NGOs and develop a strategy for data collection. In addition, an initial questionnaire was tested and refined.

A choice was made during the pilot study, to focus on two varying locations or 'embedded case studies' within Jodhpur. Embedded case study design can help incorporate sub-units of analysis that add significant opportunities for extensive analysis and enhance insights into the single case study (Yin, 2009). The goal was to illustrate the different types of farming and livelihoods represented within the district. The use of embedded cases, within a broader single-case study design has been used by many authors in drylands research (Goodrick, 2014; Kattumuri et al., 2017; Zampaligré et al., 2014). In designing embedded cases, Yin (2009) calls for a selection through sampling or cluster techniques, which are discussed below.

4.4.4 Sampling strategy: Selection of 'clusters', 'villages' and 'households'

The field research adopted a cluster sampling approach, where the population was divided into 'clusters' (geographical area), in order to take a sample of clusters (n=2), and then select a sample of cases from each cluster (n=5 villages). Clustered sampling is argued to be useful for

[54] CAZRI falls under Indian Council of Agricultural Research (ICAR), which is an autonomous organisation under the Government of India.

large dispersed populations (Yin, 2009), such as is the case in Jodhpur. The objective of cluster sampling is to ensure that enough data is gathered to give an accurate understanding of the issues under investigation and the different perspectives that are present in the study population. The district of Jodhpur constitutes seven tehsils and 10 panchayat *samithis* for administration[55] (see Chapter Three, Section 3.3). Two broad clusters were chosen for study: one in the west (Cluster I) and one in the centre of the district (Cluster II) (Figure 4.4). In Cluster I, agriculture is largely rain-fed and for subsistence while in Cluster II, agriculture is reliant on irrigation and increasingly marketed. The two clusters were chosen to illustrate the duality of farming systems in the arid regions of India. Within each cluster, the unit of analysis was the household. The key characteristics of the two clusters are presented in Table 4.2.

The research design was initially flexible while sampling within the two clusters. Due to a good response from the village *panchayat* leader (called the *Sarpanch*) in the village of *Ujaliya*, which was located in the block of Osian in Cluster II, the interviews commenced there. After 16 interviews in *Ujaliya*, it was decided that a broader sample of villages would be beneficial to gain an understanding of the issues raised. Within each cluster, five villages were therefore selected iteratively. Two criteria were used for village selection: (i) distance from the previous village studied in the Cluster to gain spatial homogeneity in observations; and (ii) receptiveness of the panchayat leader[56] to the research, which although not always necessary, was important to gain trust within the community. Within each village, 15-20 households were selected using purposive snowball sampling[57]. The value of purposive snowball sampling in hard-to-reach populations has been discussed by Young et al (2010) and Bhattacherjee (2012), and aided the process of selecting successive respondents on a daily basis.

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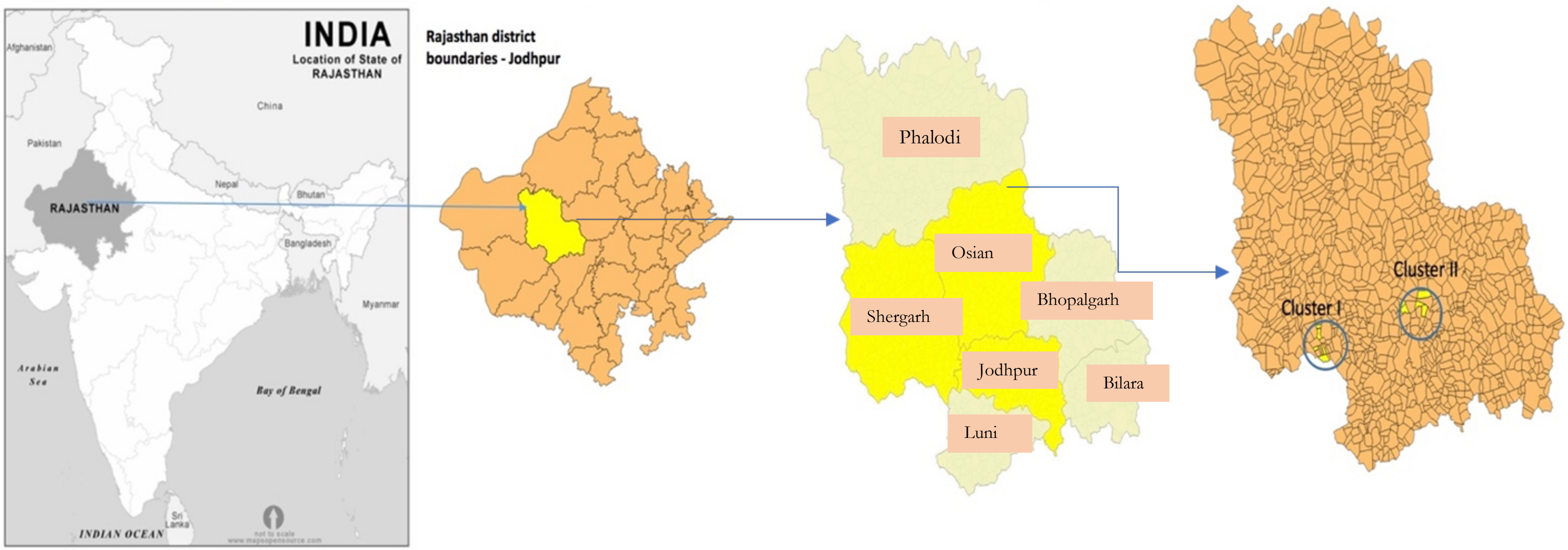
[55] One each in four tehsils and two each in three large tehsils (for administrative convenience)

[56] The panchayat leader (called *Sarpanch*) is not a typical gatekeeper as defined in development research. For instance, panchayat leaders did not control access to the villages. For instance, most respondents did not ask if we had spoken with the *Sarpach* before the interview. It was however considered an important courtesy to inform the panchayat leader of the motivations for the work and that the researcher would be present in the village for a few months.

[57] Purposive Snowball Sampling: In snowball sampling, one starts by identifying a few respondents that match the criteria for inclusion in the study, and then asks these respondents to recommend others that they know who meet the selection criteria.

Figure 4.4: Location map of India, showing the location of Rajasthan within India, and Jodhpur district (highlighted yellow). The seven blocks of ccccccJodhpur district are shown, highlighting the three that were chosen for the field study (Jodhpur, Osian, Shergarh). Following this, five villages were selected within each block to conduct the detail household interviews. Cluster I villages are located in the block of Shergarh in Balesar sub-block; and Cluster II villages are located in two blocks of Osian and Jodhpur.



Source: Maps of India (2017) and Author's own illustration

Table 4.2: Key characteristics of the two clusters

	Cluster I	Cluster II
Geographical location with respect to district/block level	Western Jodhpur – falling within the block boundaries of Shergarh and sub-block of Balesar	Central/eastern Jodhpur – falling within the block boundaries of Osian and Jodhpur
Number and names of villages selected	5 villages; Narayan Nagar, Dhadhaniya Bhayla, Khetasar, Chauthpura, Khari Beri	5 villages; Ujaliya, Bhawad, Jheepasani, Rampura Bhatiya, Chaupasani Charnan
Agro-climatic zone	Arid; Monsoon season; June–September.	Arid/Semi-arid; Monsoon season; June–September
Soil types	Desert soils and sand dunes; aeolian soil, sandy to sandy loam, calcareous	Red desertic soils, desert soils, aeolian soil, silt loam, calcareous
Average annual rainfall (1985-2014)	285.3 mm	310.5
Groundwater condition; Change in water level pre-monsoon 1984-2006 (CGWB, 2014)	Category: Over-exploited Balesar (-9.63m)	Category: Over-exploited Osian (-13.73m); Mandore (-9.02m)
Total population in selected 5 villages (Census 2011)	2630	2443
Scheduled caste/tribe population (Census 2011)	6%	25%
Total households in selected 5 villages (Census 2011)	646	425
Average no. of people per household (Census 2011)	4	6
No. of HH's interviewed	N= 84 (~ 17 households per village)	N=79 (~ 16 households per village)
No. of in-depth histories	N=5	N=5
No. of group discussions (5-10 participants)	N=2	N=2
Ethnic composition of households (from interviewed)	Dominated by Hindus, in particular, *Jats* (44%) and *Kumhars* (29%)	Dominated by Hindus, in particular, *Rajputs* (26%), *Mali* (23%), *SC/ST* (14%)
Average landholding size (among those interviewed)	5.01 ha	6.21 ha
% of farmers using irrigation in the sample	2%	81%
Major cropping seasons	Major season: Kharif; single cropping	Major season: Kharif, Rabi; Double/triple cropping
Major crops (2015-2016) (from interviews)	*Kharif* crops include mainly pearl millet (Bajra), mung bean, moth bean, sesame, *guar.*	*Kharif* crops include mainly pearl millet; *Rabi* crops include wheat, castor, and vegetables (including carrot, cauliflower, onion etc); *Zaid* crops include cotton
Major source of livelihood/income (2015-2016) (from interviews)	Semi-pastoralism that includes crop cultivation and livestock rearing (goats, cows, buffalo, sheep, camels); tree-product collection (*khejri* and *rohida*); tractor/truck driving (mostly temporary); small business	Crop cultivation; agriculture labour (on leased or non-leased crop land); pastoralism (cows, buffaloes, goats); wage labourer (construction etc)
Source of major food (2015-2016) (from interviewed)	Pearl millet, dairy, wild vegetables (watermelon, wild cucumbers /*Kachra*), tree-based vegetables (*khejri* beans), livestock meat (only *Rajputs* and Muslims), govt. rations (sugar, tea, wheat).	Pearl millet, cultivated crops (carrots, chillies, cabbage, garlic, cauliflower, wheat, pulses), market-bought foods, livestock meat, govt. rations.

Source: Collated using information from field interviews; CGWB (2013); CGWB (2008); GoR (2013)

4.4.5 Description of the two clusters

This section draws out the key characteristics of each cluster, focussing on identifying the rationale for their choice and representativeness to the research objectives. Each cluster is introduced through a field notes diary, which was written after the first visit to the area. Then, a detailed picture of livelihoods and agricultural practices represented within each cluster is presented, firstly using census information, followed by details on the households selected for participation in the field research.

Cluster I

- Notes from the field diary, first impressions of the area around *Balesar, the selected subtehsil* in September 2015

Travelling through the dusty desert lanes of Balesar, the landscape is captivating - golden silky sand dunes sprinkled with indigenous *Khejri* trees. My local interpreter tells me the trees appear barren because they are slowly being lopped for household use as is the practice this time of the year. I also notice many residents sleeping under neem trees, playing games, sifting through the millet crop, feeding livestock, all appearing to move at a listless pace. She tells me harvest season is over and that's why we see people relaxing. I see wild nilgai and two camels peeking out from the scrub, trying to feed on the few unlopped trees left. I count three completely parched open water-sources on our way into the village centre. As we move closer to the village, we pass a number of *dhanis* – group of huts (or farm houses). Each small group is located very far from the next. All the huts have thatched roofs and as I pass through each, the feeling is timeless. Only electricity wires and tractors parked outside bring me back to 2015. We stop at one of these *dhanis*, and walk towards a small cluster of huts. I soon realise not all are houses, but most of them are storage units, stuffed to the brim with millet fodder. There are two men with long twirled moustaches wearing bright turbans and crisp-white kurtas lounging under trees in *charpoys*, looking suspiciously at the car. A number of women mill about, working on small tasks. They are all veiled and wearing bright garments and silver jewellery. The women don't appear fazed as we approach, and instead many walk towards us as we approach the two men. They say, "I haven't seen outsiders like you here for years, what are you doing here? Are you lost? You can't leave without trying our famous tea".

Cluster I is located in the west of Jodhpur district and falls within the sub-district boundaries of Shergarh tehsil[58] and within the sub-block of Balesar (see Figure 4.4). Five villages Narayan Nagar (NN), Dhadhaniya Bhayla (DB), Khetasar (Kh), Chauthpura (Ch) and Khari Beri (KB) (see Figure 4.4 for village boundaries) were selected for interviews. According to the Indian National Census, the five villages account for a Total Geographical Area of around 2,089 ha, of which 55.8% was classified as net sown area (GoI, 2011). All the area 'currently sown' was recorded under the monsoon (*Kharif*) season, and no land under irrigation was reported (ibid).

[58] Tehsil is, 'an administrative division of India denoting a sub-district'

The Census reported an average of 129 households in each village, with an average population per village of around 526. The Scheduled Castes (SC) population was only recorded in three villages (NN, DB and Kh) and was around 157 (Table 4.2). Power supply for domestic use was intermittent but available in all villages. Power supply for agriculture was also intermittent and was available only in Ch and KB villages (ibid). The closest city or town is Jodhpur city, located approximately 65 km from the centre of the Cluster.

A summary of the key services and resources available in the villages of this cluster, recorded using information from the Census (2011) and observations during the field study are included in Table 4.3.

Table 4.3: Summary of key resources and services in the selected villages of Cluster I

Cluster I	Permanent pastures & grazing land	Forest land	Water - Tap	Water hand-pump	River/Canal	Tank/Ponc	Liquified Petroleum Gas (LPG)	Pukka (gravel) road	Public transport (Bus/Van)	Toilet (covered by Swacch Bharat Abhiyan)	Health Centre (PCT,	Govt. school (middle school)	Bank (Commercial/co-op)	Agri. Credit society	Self Help Group for women (SHG)	Public Distribution System (PDS) shop	Msndis (regular markets)	Community centre	Electricity (domestic)	Electricity (agriculture)	MGNREGA work allocatior
Narayana Nagar			○	○		○	○			○				○					○		○
Dhadhaniya Bhayla				○		○	○	○		○		○				○		○	○		○
Khetasar			○			○				○									○		○
Chauthpura			○	○		○	○			○						○			○	○	
Khari Beri			○	○			○			○		○				○		○	○	○	

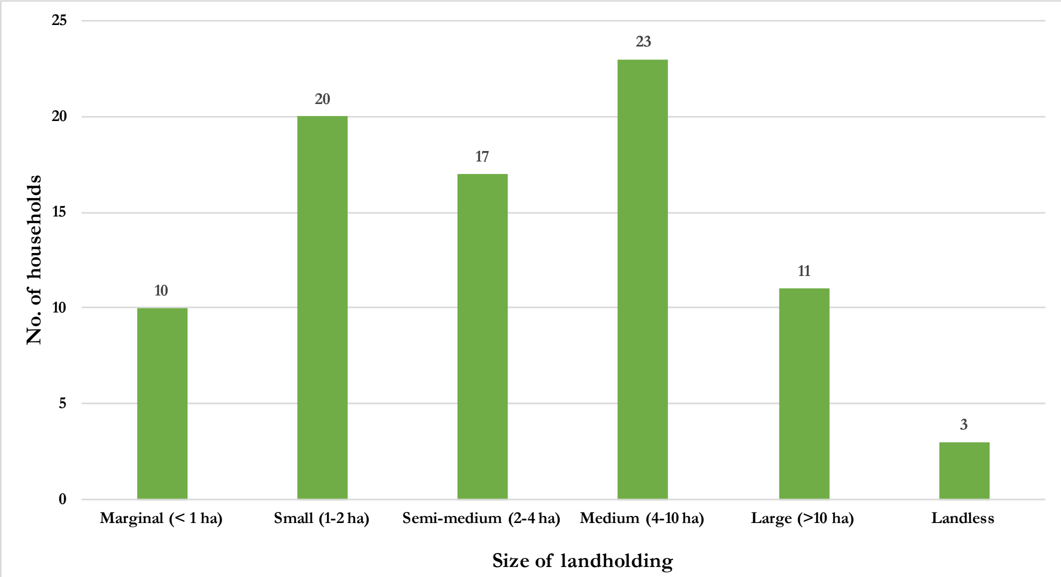
Source: Author's own

In the five villages of Cluster I, a total of 84 households were selected for interview. They were all headed by men; the respondents included 23 women (in households where the head of the household was either absent or not available for participation). The average age of the interviewee was 51, and the households had an average of 8 people, and on average only one member had a secondary school education.

Livelihoods of the respondents interviewed in Cluster I were largely dependent on semi-pastoralism, with 70% of the interviewed reporting a combination of crop cultivation and livestock-rearing as their primary occupation and source of income. More recently, migration of key male members had become an important secondary source of income. This is largely due to the demand for agricultural labour and tractors in the large irrigated farms of neighbouring Punjab.

The average landholding size of the respondents was 5 ha. A detailed breakdown of respondents by landholding size is presented in Figure 4.5. An attempt was made to interview respondents in all of Rajasthan's land size classification categories. A majority of respondents were small to semi-medium farmers. The 11 large farmers interviewed owned about 15 ha of land each (on average).

Figure 4.5: Households interviewed by size of landholding in Cluster I (in ha)[59]



Of the 84 households selected, cropping was mostly done in one season – *kharif* - and the key crops grown were: pearl millet (*bajra*), pulses of moth bean (*moth*) and mung bean (*mung*), cluster bean (*guar*) and, if the rainfall was good, sesame (*til*). By September, all the crops are harvested and apportioned. A large portion of the yields is stored for consumption at home until the following cropping season which is a year later; a smaller portion is stored for fodder, and the remainder, if in excess, is stored in purpose-built storage units (*kothas*) for drought years (Picture 3.3). Cropping is mainly for subsistence with only five of 84 households selling a portion of their yield, mostly sesame, over the previous five cropping seasons. In addition, four households in the villages of KB and NN had recently (in 2014) invested in irrigation infrastructure[60].

Livestock typically included a combination of goats (averaging 10-20 per household) and cattle (averaging two cows and/or buffaloes per household). Buffaloes are the most efficient milk and butter fat producers; they are also the most expensive livestock and have grown in value in Jodhpur due to their role in marriage dowry (given by the bride's family to the groom's). Seven households continued to rear sheep for their wool. Due to the sandy dune landscape and remote location, until 20-30 years ago camels were the main form of transportation in this

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[59] Classification of landholding, into small, medium, large varies by state in India. A landholding classified as large in one state may be a medium landholding in another state.

[60] Power infrastructure for domestic use has been present since the early 2000s but infrastructure extending this power to the agricultural fields has been poor in this region. As per the Census (2011), mentioned in previous page, there was no power for agriculture in the village of NN, however by the time of the field study (2015-2016) electricity for agriculture in the fields of NN was developed.

cluster. However, at the time of this research, only two of the households selected for study owned camels.

A typical household in the cluster had around 40 trees on their fields and homesteads. The trees included some combination of *P. cineraria* (*Khejri), T. undulata (Rohida), Kumquat (Kumat)* and *Z. mauritiana* (*Ber)* in the field, and Neem and *A. nilotica* (*Desi Babul*). In addition, there were randomly scattered *P. juliflora* (*Angrezi Babul*) surrounding most farms and village lands. While *P. juliflora* is technically a non-native species (indeed some respondents referred to it as a weed), its main use value is for fuelwood.

The social structures in all the villages of Cluster I were heavily rooted in their traditions. Large joint families live together (*dhanis*) or close to each other in dispersed homesteads. The heavy reliance on these inter-and intra-household relationships and the focus placed on self-reliance of *dhanis* comes from: (i) the large distances between houses in this remote location and, until recently, the lack of road and transport facilities; and, (ii) their experiences of living with drought. The cluster initially appeared very patriarchal, with the position of women constantly undermined through child marriage, purdah and exclusion from public life. However, fieldwork revealed a more complex situation, which will be discussed in Chapter Six.

Picture 4.1: Photos from Cluster I showing topography and landscape

Source: Author's own

Cluster II

- Notes from the field diary (March 2015), first impressions of the area around *Rampura Bhatiya*, one of the villages in this cluster

We are in the village of *Rampura Bhatiya*, where we sit down with the self-proclaimed 'carrot king'. He is surrounded by 10 of his men, all labourers in his field. He is jovial, regaling us with stories of how much money he made in the last cropping season by selling carrots in faraway Mumbai. We get back to the main village centre and undertake a day long walkabout. I pass large farms, sprinklers spraying water onto lush green crops of mustard and carrot, all at different stages of the cropping cycle. I also pass fields with parched castor crops, and many large sections of land inundated with *P. juliflora* and weeds, clearly in disuse. I spot a lot of activity: women weeding, men tilling, even a herd of cows push us out of the way, seemingly in a hurry to get somewhere. Most farms are heavily barricaded. I stop at one such farm where I see a few men huddled in a corner trying to jumpstart their diesel engine. They are all wearing trousers and jeans, and I don't spot the famous Rajasthani 'moustache'. They don't seem surprised to see us. I wave at two women in bright pink veils peeping at us from behind the windows of a small *pukka* (concrete) home. As they catch me waving, they immediately disappear and one of the men frowns and tells me not to look at the women. When I ask him about the heavily secured farm boundaries, he replies that's to keep away wild animals and, importantly water-hungry farmers looking to load up on some extra water when no one is looking. He says, I don't trust anyone here anymore and looks at us and says, 'who are you people? Are you here to sell us seeds?'

Cluster II is located centrally in Jodhpur district, falling within the tehsil boundaries of Osian (four villages) and Jodhpur (one village) and within the sub-blocks of Osian, Bawari and Mandor (see Figure 4.4). Five villages were selected for interviews and included the villages of Chaupasani Charnan (CC), Rampura Bhatiya (RB), Ujaliya (Uj), Bhawad (Bh), and Jheepasani (Jh) (see Figure 4.4 for village boundaries). According to the Indian National Census, the five villages account for a total geographical area of around 6,197 ha, of which 42% was classified under net sown area, and 50% was reported as irrigated land (GoI, 2011). The Census records also show around 8% of the TGA to be under permanent pastures; however, the field study found this was largely outdated/inaccurate[61] and this will be discussed further in Chapter Six. The Census accounts for an average of 85 households in each village, and an average population of around 489 per village. The SC/ST population was recorded in all five villages and included 483 SC and 125 ST members. Power supply for both domestic and agriculture use was available in all villages (on average 22 hours of domestic electricity and 7 hours in the

[61] During the field visits, the Census information on net sown area and area under permanent pastures was found to be inaccurate. This could be due to three reasons (i) the information is outdated i.e Census information was probably collected before 2011, and by the time of these interviews (2015-2016) that information had changed significantly; (ii) village boundaries are often re-drawn in India. During the interviews (2015), one of the villages was transferred from one revenue tehsil to another; or (iii) The census information is inaccurate (a few respondents brought this up during interviews) as panchayat officials and record makers are often under pressure to report certain findings.

farms). The closest town is Jodhpur city, located about 30 kms away by road from the centre of the Cluster.

A summary of the key services and resources available in the villages of this cluster, recorded using information from the Census (2011) and observations during the field study are included in Table 4.4.

Table 4.4: Summary of key resources and services in the selected villages of Cluster II

Cluster II	Permanent pastures & grazing land	Forest land	Water - Tap	Water hand-pump	River/Canal	Tank/Ponc	Liquified Petroleum Gas (LPG)	Pukka (gravel) road	Public transport (Bus/Van)	Toilet (covered by Swacch Bharat Abhiyan)	Health Centre (PCT	Govt. school (middle school)	Bank (Commercial/co-op)	Agri. Credit society	Self Help Group for women (SHG)	Public Distribution System (PDS) shop	Msndis (regular markets)	Community centre	Electricity (domestic)	Electricity (agriculture)	MGNREGA work allocatior
Ujaliya		○	○			○	○		○	○	○	○				○		○	○	○	○
Bhawad	○		○			○	○	○	○	○		○	○	○	○	○	○	○	○	○	○
Jheepasani			○			○	○			○									○	○	○
Rampura Bhatiya	○		○			○	○	○	○	○		○	○	○	○	○	○	○	○	○	○
Chaupasani Charnan			○			○	○	○	○	○		○				○		○	○	○	○

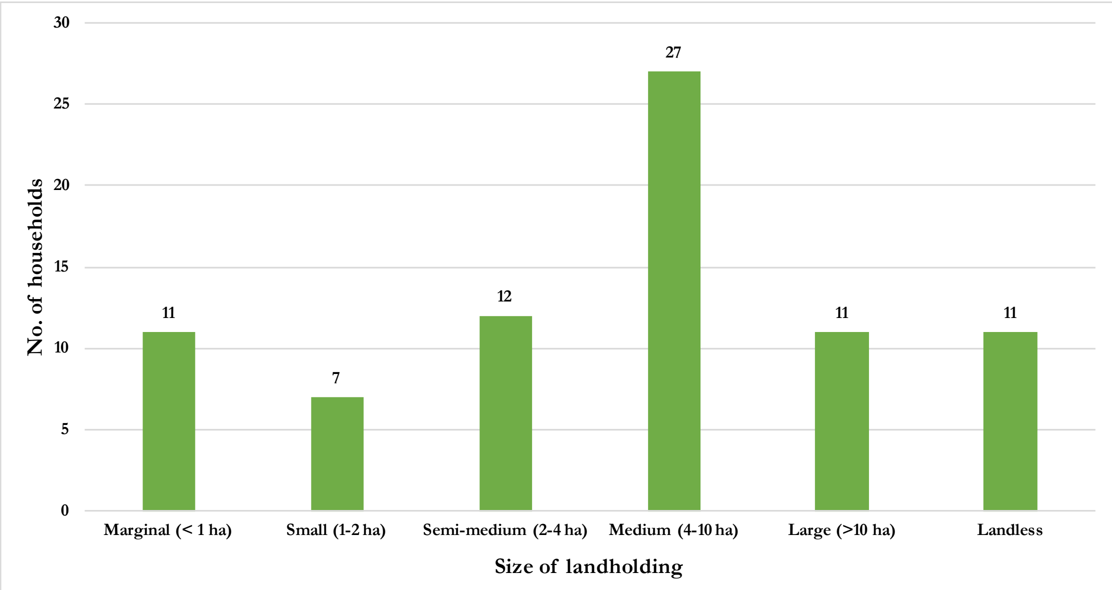
Source: Author's own

A total of 79 households were selected for the interviews in the five villages, all of which were headed by men. The respondents included ten women (in households where the head of the household was either absent or not available for participation). The average age of the interviewee was 49, and the average household size was 9, of which only one member (on average) had a secondary school education.

Livelihoods in Cluster II were primarily dependent on cropping, 72% of households described it as their main source of income. Cropping was done in two or three seasons. *Kharif* crops grown included pearl millet (*bajra*), pulses (*mung, moth bean*) and cluster bean (*guar*). By September, *kharif* crops are harvested and land is prepared for the *rabi* (winter) crop. Key *rabi* crops grown were wheat, rapeseed, mustard, cumin, and vegetables (carrot, cauliflower, garlic, chillies). A third *zaid* (summer) crop, largely constituting of cotton was grown by a few households. *Kharif* crops were largely used for home consumption and for fodder and most of their *rabi* crops were sold in the market. A majority (81%) of respondents relied on irrigation; 59 of the 64 households involved in *rabi* cropping, had their own source of irrigation (tubewells), while the remaining five either paid for groundwater from a neighbour or leased land with a tubewell.

The average landholding size was 6 ha. As shown in Figure 4.6, an attempt was made to interview respondents in all of Rajasthan's land size classification categories. A large majority of those interviewed were medium farmers. Six of the 11 landless respondents were leasing land from other irrigated farmers, while the remaining five were working as labourers in irrigated farms. There were more medium and large farmers than in Cluster I, and these were managed by fewer people. For example, a large farmer in Cluster II owned approximately 30 ha of land on average - double that of a large farmer in Cluster I.

Figure 4.6: Households interviewed by size of landholding in Cluster II (in ha)[62]



Livestock typically included a combination of cattle (averaging 1-2 per household) and buffaloes (around 2-3 per household). Goats were less popular, with less than 50% of the interviewed households owning goats (2-4 goats per household)[63]. Five households had sheep and two owned camels.

A typical household in the cluster had around 10-15 trees on their fields and homesteads. The trees included a combination of *khejri, neem* and *rohida* on the field and *desi babul* on their homesteads. In addition, there were significantly more *P. juliflora* trees in the fields and surrounding village lands in this Cluster[64].

Social structures in all the villages of Custer II, while still rooted in tradition, were less reliant on joint families. Households were generally clustered around the village centre and distances between households were smaller. There were many immigrants in Cluster II, many of whom

[62] Classification of landholding, into small, medium, large varies by state in India. A landholding classified as large in one state may be a medium landholding in another state.
[63] Goats are more difficult to stall-feed and as irrigation takes up more crop land, there is little area left for grazing goats.
[64] Cluster I reported *P. juliflora* was not that damaging to their crops but Cluster II reported *P. juliflora*, as a key indicator of degraded soil and crop loss (these differences will be discussed in Chapter Five and Six).

had migrated from the drier western areas of Rajasthan, drawn by the prosperity offered by irrigated farming. There were more irrigated plots of land, fewer trees and more closely located village homes in Cluster II in comparison to Cluster I.

Picture 4.2: Photos from Cluster II showing topography, landscape, and cropping

Source: Author's own

The inherent complexity present in the two diverse socio-ecological systems of Cluster I and Cluster II illustrates the need for empirical fieldwork as a central data collection tool, for a better understanding of the relationships in their natural settings. Further, limited information exists on the details sought, especially in the proposed study region. The information that was available on resource use and the cultural practices of the people of the desert was outdated (from the 1980s). Rapidly changing livelihoods, especially in the light of wide-ranging climate variability, also meant that census data, collected every 10 years, is unlikely to be robust.

4.5 Data collection

The data generated during the eight-month fieldwork included household interviews (n=163) conducted across 10 villages in the two clusters the Jodhpur district, focus group discussions (n=4), in-depth case histories (n=10), informal discussions and observations. In addition, secondary data was collated from a range of different sources. Each of these methods and their practical applications are discussed below. During the fieldwork, a recording device was not used, as respondents were not comfortable with this. All the information was handwritten and thorough field notes were summarised at the end of each day.

4.5.1 Secondary data collection

To help place the findings in context, secondary data was used to collect background information prior to, during, and after the fieldwork. Some of the secondary information sources were available online as reports, official documents and publications. Others were sourced from the local offices and libraries while in Jodhpur.

(i) **District, State and National level** data was gathered from various sources including:

- The CAZRI library in Jodhpur city: Information from CAZRI reports on the state of natural resources and the process of dryland degradation, and from basic and applied research on the development of farming systems in arid agro-ecosystems.
- The Indian Space Research Organisation (ISRO) or National Remote Sensing Centre (NRSC): The centre has a district-level base in Jodhpur city and information was collected on the state of land degradation in India and Rajasthan.
- The Indian National Census, Ministry of Environment & Forests, Department of Economics & Statistics, Central Groundwater Board, Central Pollution Control Board and other national and state government sources. Some of this information was available online and some were sourced from local offices in Jodhpur.
- Other national level research organisations such as Central Research Institute for Dryland Agriculture (CRIDA), National Innovations on Climate Resilient Agriculture (NICRA) and Institute for Social and Economic Change (ISEC).
- International development organisation reports by the UNDP, FAO, World Bank and UNEP among others. This information provided valuable context on a number of key socio-demographic and agricultural statistics.

(ii) **Village level** secondary data was limited but available through the Indian National Census, which provides a database of basic statistics on demographics, services provision, and land use at the village-level. The National Census is conducted every 10 years, the most recent was in 2011.

(iii) **Meteorological information** was collected from the Indian Meteorological Department (IMD) to understand trends in key climatic variables. Rainfall trends and temperature trends available for approximately 50 years (1965-2015) were analysed through station data for Jodhpur district, using the weather stations closest to the two clusters. Further details are provided in Chapter Five.

The different methods used in collecting primary data are detailed in sections 4.5.2 to 4.5.5.

4.5.2 Household interviews

An interview is one of the most common research tools used in qualitative research (Warren & Karner, 2009). Interviews were conducted using questionnaires that were developed after an initial review of secondary literature from the region, and then enhanced during the pilot study in March/April 2015. The pilot study showed that an iterative, open-ended, semi-structured interview format facilitated discussions with participants, and helped to gain their trust and open up during discussions. The format enabled collection of both qualitative and quantitative information about respondents' socio-economic histories, the state of key resources, resource-use patterns and perceptions of climate change and variability, and sources of vulnerability. The questionnaire also sought to gain knowledge into communities' participation in various institutional support mechanisms, and their views on the involvement of local governmental organisations. In addition, open-ended questions helped gain insight into their cognisance of the interactions between the climate and land resources in shaping their adaptive behaviours and livelihoods.

The questionnaire followed a uniform structure and is included in Appendix III. At the outset, open-ended informal discussions were helpful in introducing the research topic. Following this, structured information was collected on several key demographic, socio-economic and livelihood factors which included: size of their family, level of education, size of their land, area irrigated, and the quantity of fertilizer used per hectare. This helped to set the context and to create a profile of each household, with the expectation of quantifying some of the responses. Follow-up questions within each topic used a semi-structured format, which was designed to be flexible and therefore facilitate an exploration of relevant issues.

The interviews varied in length and on average were an hour long. Most interviews were conducted in *Marwari*, the local language in the region, through a local interpreter and in some cases were conducted in *Hindi* (India's official language). Interview responses were translated to the researcher during the interview and notes taken in English. Language is the primary means of reflecting social and cultural practices (Steger, 2004). Thus, the role of the interpreter is not only one of language translation but also that of a cultural mediator between the researcher and the respondents (ibid.). The interpreter was selected through recommendations from CAZRI-based scientists and was present in all the interviews. Of the three recommended interpreters, a woman was chosen because:

(i) She was a local, from a village in Jodhpur district, and therefore familiar with local customs. Choosing an interpreter from a village was also beneficial since she spoke the 'informal' language of the region, as opposed to the formally taught *Marwari*, spoken by educated and city dwelling people.

(ii) She had previous experience of collecting socio-economic information using household interviews conducted for the local arid zone research institute (CAZRI).
(iii) A female interpreter would be more beneficial in speaking with women of the community.

Prior to beginning the interviews, thorough discussions were had with the interpreter on the aims of the research, the goals of the fieldwork, and the approach to be used in translating the information. The experience and knowledge of the female interpreter provided substantial information regarding the social and cultural traditions in the villages, as well as knowledge of how different responses are to be interpreted and understood. The challenges of using an interpreter are discussed in section 4.7.2.

The interview responses are signposted throughout this thesis using cluster number, village initials and household number. For instance, household 1 from the village of *Khetasar* in Cluster I is referred to as I_Kh1, household 2 as I_Kh2, and so on. Appendix IV provides a complete list of respondents for the entire sample. Within a household, the head of household (HoH) was the preferred respondent. Where the HoH was unavailable, the interview was conducted with the responsible household member present. Where women were not comfortable to speak in front of men, they were interviewed separately.

The household questionnaire was also used as a basis for developing questions for the in-depth histories and focus group discussions.

4.5.3 In-depth case histories

From the interviews, five households were selected in each cluster for an in-depth life history. A case history generally relates to a respondent's detailed account of his/her life, including, personal history, experiences, challenges, and opportunities. Each life history took over a day; the researcher spent time with the family, speaking to as many people within the household as possible, and going back on successive days if needed. In some cases, households with issues relevant to emerging themes in the research were chosen. In other instances, a household offering atypical information was selected. For instance, a household in *Khari Beri* village (I_KB17) had recently invested in solar power and offered information that was atypical. A list of households selected for detailed histories is also provided in Appendix IV.

4.5.4 Focus groups

A focus group involved a small number of participants (the size of the group varied, but was usually around 5-15 people) and discussions were conducted in a semi-structured manner focussing on a particular set of topics (Bryman, 2001). Authors including Cameron (2010) and

Wilkinson (2004) have highlighted that the group setting provides respondents with the opportunities to engage their thoughts and opinions with others in the community, some from their own socio-economic backgrounds and others from different backgrounds.

Focus group discussions were conducted in the final stage of the field work and helped to clarify if household-level concerns translated into broader concerns felt at other scales such as village and cluster. Two focus group discussions were held in each cluster, and were conducted in December 2015 and January 2016, after a short-break taken to organise and document information from the completed household interviews. Focus groups explored issues of land degradation, newer climatic variables, ideas of vulnerability, resilience and adaptation, and institutional complexities. Appendix V provides the questionnaire format followed during the focus group discussions. For the vulnerability analysis, focus groups were asked to assign weights, using a participatory exercise designed to help attach weights to primary vulnerability criterion. Each criterion was explained to the communities and presented in boxes drawn on the ground in chalk, each box representing one criterion. The participants were then given 100 small sticks and were asked to distribute the sticks within each box (criterion). As with the interviews, this information is signposted as I_FC1, I_FC2 etc.

Picture 4.3: Focus group discussion in the local panchayat office in Bhawad village in Cluster II with three men and three women and a male researcher. In the presence of men, women whisper and therefore were seated closer to the researcher and female interpreter

As in the household interviews, focus group discussions were also conducted in *Marwari*, the local language, with the help of an interpreter. In addition, assistance was taken from a local male researcher. The male researcher was a good strategy to gain maximum interest for the meeting and also to ensure that the more patriarchal men would not just leave (the limitations of female researcher, working through a female translator are discussed in more detail in Section 4.7). Informing the village panchayat chairman in advance about the focus group discussion helped bring together varying perspectives, including an equal number of male and female respondents.

4.5.5 Informal conversations and observations

Valuable insights were gained through observations and informal interactions throughout the field work. This included informal conversations with scientists and policy makers in the region, who were often more comfortable exchanging information informally. These discussions helped gain a better understanding of the work and likely difficulties to be expected in the field in rural Rajasthan. Another set of informal dialogues took place with village panchayat members, who were wary of taking part in formal recorded interviews. In addition, informal daily conversations with the interpreter helped provide a comprehensive understanding of the daily living conditions and cultural context of each household.

Observations were recorded through a field diary and photographs. Data gathered through observations enabled triangulation of information gathered through other techniques and to check discrepancies between what people said and what they did in practice.

4.6 Data analysis and writing up

Triangulation "involves using several methods to reveal multiple aspects of a single empirical reality, a discovery process designed to get at an objective truth that may be systematised as a formal theory of social structure and process" (Miller & Fox, 2004: 35). Triangulation of information is helpful in resolving conflicts between data collected using diverse mixed methods.

Once the information was collected, it had to be effectively coded, analysed and presented in a way that best represented the data. The following sections give a brief sketch of data analysis and reporting.

4.6.1 Analysing complex and abundant information

Yin (2009) states that, in using a case study, a researcher can be flexible in choosing an analysis based on his/her own style of thinking as long as careful considerations is given to alternative interpretations. All primary data collected were analysed using two different methods. Initially, an Excel spreadsheet was used to input structured, quantitative information from the 163 household questionnaires. Next, as is common in qualitative research (Cope, 2010), qualitative information was coded. Using inductive reasoning, used data and concepts from each interview and linked them to a theme, based on previously identified constructs from theory (i.e. sensitivity and adaptive capacity from the IPCCs vulnerability framework), as well as from emerging patterns within the interviews (i.e. issues of resource access and sustainability, which were not identified in the theoretical review). These included themes such as 'land degradation', 'climate', 'agriculture', 'groundwater depletion', 'agro-forestry', 'government support', 'women', 'access'. In addition, vulnerability themes of 'sensitivity' and 'adaptive capacity' were developed. The coding of descriptive qualitative data was done manually from the field notes and then individual themes were colour coded for ease of analysis. This descriptive coding process allowed for easy categorisation and deliberation. The household code used in the excel sheet was also included in analysing the qualitative information for ease of comparing the more and less structured information.

4.6.2 Analysis and presentation

The data was analysed keeping in mind the links and reciprocal feedback effects established in the conceptual framework (Figure 4.2). The key stages followed in the data analysis are in line with the three research questions proposed earlier in this chapter and presented in chapters Five, Six and Seven. They are illustrated in Table 4.5.

Table 4.5: Structure of the analysis and presentation of the results

	Aim of analysis	Analysis	Data	Results chapter
RQ1	Establish significance of dryland degradation and climate risks to agriculture and livelihoods	- Community perspectives and empirical evidence on land degradation and climate change - Community perspectives on the linkages between land use, livelihoods, dryland degradation and climate change	Secondary data Primary data from household interviews	Chapter Five
RQ2	Develop a vulnerability framework for drylands and test the framework in Jodhpur	- Analysis of results from the agriculture and livelihoods vulnerability index - Qualitative vulnerability analysis	Primary data from household questionnaires (quantitative and qualitative)	Chapter Six
RQ3	Develop context specific findings to aid in better targeting of adaptation planning	- Analysis of information from RQ1 and RQ2 to develop specific vulnerability typologies that highlight the relationship between dryland degradation and vulnerability	Secondary data Primary data from household interviews	Chapter Seven

4.6.3 Reporting results

In reporting results, outcomes are typically discussed in relative rather than absolute terms. This is true particularly for the quantitative results presented from the household questionnaire. For instance, in the vulnerability analysis (Chapter Six), one household is vulnerable with respect to other households sampled in Cluster I[65]. This reflects the research goals of this thesis, where the intention is not to provide definite statistically significant answers, but, explore the varying range of experiences and conditions associated with dryland degradation and its central theme of vulnerability. Therefore, where quantification was possible results were discussed in a specified manner, for instance, 70% of households interviewed use hybrid seeds. Additionally, where quantification was not possible or considered ineffectual, results were discussed in non-specific terms (Joakim, 2013). These are detailed below, so as to provide clarity for the reader in understanding the results and discussions presented.

(i) **'few'**, referring to a small percentage of respondents;
(ii) **'some'**, referring to when the number of respondents was not known or not quantified, for instance, responses from group discussions or notes from field diary;
(iii) **'a number of'**, **'many'** or **'several',** referring to where more than a **'few'** were in agreement (but not enough to form a majority). Often these were responses noted in the field diary, that recurred consistently from the household interviews;
(iv) **'majority'**, refers to more than half of the respondents.

4.7 Notes from the field: Predicaments of fieldwork in Jodhpur, Rajasthan

In any developmental fieldwork, every research setting will be different in terms of the geographical, political, social and cultural settings. Whether at home or abroad, a researcher is likely to face significant challenges, in negotiating danger, and managing the complexity of collecting information in an unfamiliar setting (Tomei, 2014). As with any research, I expected many difficulties in the field, that included a number of ethical, methodological and logistical challenges. I also expected several cultural challenges of working in areas where religion, caste, class, and gender play a key role in day-to-day interactions.

4.7.1 Research ethics

An awareness of the ethical issues presented by the research is important, especially when utilising a methodology that includes participants in their homes (Gent, 2014). The rights of participants to informed consent, privacy, safety and confidentiality were therefore observed. As a general rule, all information collected was gathered with adequate consent from the participant. Respondents were asked to only provide information that they were willing to

[65] This is common in vulnerability assessments, where vulnerability is a relative measure (Downing et al. 2001), relevant to the selected scale of study.

share. Respondents were informed before the interview that their personal information would not be made public, and it would not be shared with the government (a particular concern in the region) or any other governmental organisation. No data on income was collected, as it is generally deemed inappropriate to raise this topic in this region. In all the interviews, respondents were informed that the work was strictly for research purposes and not for any commercial use, and no monetary benefits would be provided for their participation.

4.7.2 *"Can you speak Hindi?"*: The role of the interpreter

This research relies heavily on community derived information and knowledge. There were therefore several challenges posed by language barriers in obtaining accurate translations and interpretations of their words. The role of the interpreter was crucial. While the interpreter was skilled, experienced, and responsive to suggestions, there remain chances of misperceptions and misinterpretations.

These challenges were greater in the initial stages of the work; it takes time for the expectations and the logistics of daily field work to become established. During the interviews, there were times when the interpreter would skip over certain questions or did not adequately follow-up on certain issues. In some instances, the interpreter presented the question in a leading manner. As a result, a few initial interviews had to be removed from the final data set due to concerns of validity. Importantly, I was present during all the interviews, in-depth case histories, and focus group discussions, which allowed me to provide immediate feedback to the interpreter. Many of these challenges were resolved as the field work progressed.

Further, the language of *Marwari* shares many lexical and structural similarities with *Hindi* (Chacko et al., 2012), a language I am familiar with. My knowledge of *Hindi* allowed me to understand and interpret many of the responses given in *Marwari*. This became easier to do as the field research progressed and the language structure and key words became familiar and clear. Due to my familiarity with the language of *Hindi*, I was also able to conduct some of the interviews myself, with only minor assistance from the interpreter.

4.7.3 *"How many children do you have?"*: Being a female researcher in Rajasthan

In conceptualising my research and conducting fieldwork, the main question that everyone asked me and I asked myself was – is this going to be safe? I am from India (albeit from the South) and have lived in India for a major part of my life, which means I am familiar with the socio-political and cultural landscape. Pio and Singh (2016) highlight that familiarity does not necessarily mean a sophisticated understanding of potentially unsafe situations and instead could lead to a heightened sense of caution and worry about what could go wrong during fieldwork. I also conducted this research at a time when large reports of violence on women in

North India were in the news. Thus, one of the main issues I faced relate to being a female researcher in the male dominated regions of western Rajasthan. Since I chose a local female interpreter, local scientists in the region told me to also take along a man, if possible, to ensure our safety. Keeping in mind these concerns, I chose a local trusted male driver to take us on our daily travels.

In conducting my interviews in a patriarchal community, I had to accept and move beyond questions regarding my marital status, my education, and why I did not have children at my age. While initially irksome, I soon realised I was also asking intrusive questions, and I was perhaps being equally discourteous. I needed to understand the social landscape I was in without being judgemental. Furthermore, being a woman with a female interpreter provided me access that a male researcher or a male interpreter probably would not get. I spent many hours with women, in the fields and inside their homes, gaining perspectives on their lives and how they view their role in society. Most shuddered to think I did not know how to make *rotis* (bread), and a few took it upon themselves to teach me. The men thought I was amusing and naïve, and trusted me with information that they may have been unwilling to share with a male researcher.

I faced other disadvantages as a female researcher in the city of Jodhpur, where I stayed for much of my fieldwork. In Jodhpur city, I struggled repeatedly to gain access to information from local scientists and governmental organisations. I was acutely aware that I was not taken seriously and I was told on numerous occasions that I was too young to have access to this data. I eventually resorted to asking a local male contact to obtain data. Upon reflection, my initial concerns were rooted in my preconceptions, I realised it was easier to approach people in rural areas than in the city.

4.7.4 *"What caste do you belong to?"*: Dilemmas with caste and other sensitivities

As I set forth to do my pilot study, I did not have any questions of caste on my long list; my city-education told me this was an offensive question. I realised within the first few interviews that my caste was more relevant than, for instance, my name. Initially, I found this distasteful and disruptive. Depending on who I was interviewing, I was asked to sit a certain way (with respect to the respondent), to say 'hello' in a certain manner and I was asked at times to cover my hair. It soon became clear to me that the respondents were not being disrespectful, rather, they were trying to understand how to relate to a stranger without being disrespectful. Rajasthani people are proud of their caste, whether they are the most elite, '*Rajputs*', or from the lower caste of '*Meghvals*'. Their caste tells the story of their history and struggles better than they can. Singh (2014: 88) describes her (similar) experience of conducting fieldwork in Rajasthan, "the caste question was as natural as a handshake, it helps a villager place himself with respect to you, it helps people to adhere to social norms and not overstep, or underplay". As I illustrate later in this thesis, societies continue to organise themselves according to caste and this determines access to resources and government support. Understanding the significance of caste was therefore an essential part of the research.

4.7.5 *"Are you from the government?":* Managing suspicions and hopes

National-level programmes such as provision of electricity, piped water supply, and the recent *Swacch Bharat Abhyan* for improved sanitation are all programmes that have made an impact in rural Rajasthan. Despite this, respondents in this area were highly impoverished when measured against almost all traditional development indicators (UNDP, 2009). Farmer suicides, especially in western Rajasthan are weekly national news, with some travelling to the capital of New Delhi to hang themselves at government rallies (Ghosh, 2015). In doing so much to get the governments' attention, communities have large expectations of what the government will do next to better their situation (Singh, 2014). A common question I was asked was whether I was making a list of those who qualified for crop compensation for the government[66]. I soon realised, in a region where there was little to no knowledge of English, the word 'survey' was known by all. In their minds, a survey meant the government was collecting information to help the most vulnerable. It was difficult to witness their disappointment when telling them I was only doing research for academic purposes. My interpreter had a more positive outlook, telling them I would write about them and not just the Government of India but even the 'people in London' would acknowledge their issues. Managing their hope and aspirations was by far the most challenging aspect of this research. Listening to the problems they confronted on a daily basis, while unable to offer any assistance, was a difficult daily hurdle.

4.7.6 Researcher as an external observer: Managing researcher-subject power dynamics

It is important when conducting fieldwork to turn the spotlight inwards on the researcher, reflecting on the research often, as it helps to critique the researcher's practice and enhance mindful action (Pio & Singh, 2016). While in the field for long periods of time, it was difficult to disengage. The researcher can often be placed within the research frame and can become a member of the community being studied. Denscombe (1998: 208) notes that "the researcher plays a significant role in the production and interpretation of qualitative data". This is often referred to in qualitative research as reflexivity, which is a methodology whereby the researcher at times becomes the focus of enquiry, and scrutinises progress (Freshwater & Rolfe, 2001). I constantly reminded myself to be alert regarding my position within the research, and whether

[66] Crop compensation is provided to farmers who have lost a majority of their crop yields in the previous cropping season

and how I was impacting on it. This helped me stay critical and enabled me to continue to raise questions, and stay "open to new theoretical and practical possibilities" while in the field (Freshwater and Rolfe, 2001: 534).

4.8 Conclusions

Overall, this chapter has outlined the use of mixed methods to develop a multi-scale approach to research design. Household interviews were used to focus on individual factors, focus groups provided community-level insights, and secondary data was used to construct broader-level, district, state and national context to the research questions. Analysis focused on the use of data triangulation, and promoted a holistic understanding of dryland degradation and vulnerability. The chapter also emphasised the challenges posed by the research in terms of ethical conundrums, an acceptance of the intricacies of rural community life while ensuring an adequate representation of the different participant's voices. The following three chapters will present findings resulting from application of the research methodology presented here.

5. Land Degradation and Climate Risks: Community Perspectives and Empirical Evidence

The focus of this chapter is on dryland degradation in arid Jodhpur. The analysis pays particular attention to how the use of land resources is shaped by the drought-prone and fluctuating environment, with looming projections of intensifying climate variability and climate change. While climate variability and climate change are routinely identified as key factors driving dryland degradation, a number of uncertainties exist in what we know about the links between the two and how they interact in different dryland settings (Gore et al., 2011; Mortimore, 2009; Stringer & Reed, 2007; Tarrasón et al., 2016; Twyman et al., 2011). Recent research emphasises "the urgent need to elucidate these links, so that land users and policymakers can respond in timely and effective ways" (Reed & Stringer 2015: 5).

This chapter addresses research question one: **How are dryland degradation and climate risks impacting on agriculture and livelihoods in Jodhpur?** In particular, as discussed earlier in this thesis, previous analysis of the drivers of dryland degradation in the study area of arid Rajasthan have been simplistic. A more detailed exploration is needed to clarify the causes and consequences of dryland degradation. Dryland degradation in this chapter is viewed as a synthesis of the complex interactions between climate, ecosystems, and social systems within inherently dynamic socio-ecological systems (Behnke & Scoones 1992; Behnke and Mortimore, 2016). By providing insights into the synergies and feedback effects between climate change, land use, and land degradation, this chapter aims to bridge some of these gaps in literature and contributes to scientific knowledge about the arid zones of Jodhpur, India.

The analysis incorporates local knowledge and lived experiences of local communities, and where possible triangulates their perceptions with meteorological trends and other secondary data. The information presented in this chapter uses district level secondary data and primary data collected in the two selected clusters of Jodhpur (Cluster I: Arid/rain-fed; Cluster II: Arid/irrigated).

The research question is addressed through a number of objectives that are structured as follows:

- Section 5.1 focuses on the extent of dryland degradation in western Rajasthan and Jodhpur district, as estimated by key secondary sources from the Government of India, and highlights the lack of clarity in measurements;
- Section 5.2 analyses key climatic variables of relevance to agriculture and livelihoods in the region, and examines trends using meteorological information for the two clusters;

- Section 5.3 illustrates how dryland degradation and climate risks are perceived by local communities. This section will demonstrate how key variables examined using secondary data translate into field level complexities. The section will explore if community perspectives are a good indicator of larger scale trends. Importantly, the analysis highlights newer climatic trends shared by respondents which are not yet visible in the observed meteorological data;
- Section 5.4 presents factors driving dryland degradation from the perspective of communities and explores them under the two umbrellas of climatic factors and land use, management factors;
- Section 5.5 draws on qualitative information from the household interviews to gain better insights into some of the distinctive interactions between climate variability, land use and land management practices in contributing to dryland degradation;
- Section 5.6 highlights the important role played by policy in managing and at times driving the interactions between climate variability and dryland degradation; and
- Section 5.7 concludes this chapter with an overview of the key findings.

5.1 Observed status and trends in dryland degradation in Jodhpur

This section focuses on the extent of dryland degradation in Jodhpur district using estimates from secondary data. Dryland degradation in India is generally referred to as 'desertification'. Its measurement is driven by recent improvements in India's remote sensing capabilities, and continues to be associated with top-down measurements of key biophysical processes that contribute to 'desertification'. There is a lack of critical thinking in the interpretations of these results at the ground level; most degradation processes are attributed primarily to the 'Anthropocene' and people are often cited as agents of degradation. Despite this focus on people as primary drivers of degradation, studies analysing the implications of human intensification on land degradation in the Thar desert are limited to a few published studies (e.g. Tsunekawa et al., 1997; Varghese & Singh, 2016) and disparate local research reports from arid zone research institutions (e.g. CAZRI).

As discussed in Chapter Three (Section 3.1.2), two studies are commonly cited, both supported by the Government of India. They measure land degradation using differing concepts and estimation methods.

- **NBSS&LUP:** The NBSS&LUP estimate land degradation as a function of soil erosion. Accelerated soil erosion is a major factor responsible for degradation of land (Lal, 2001). Studies have shown that soil erosion contributes to around 83% of global degraded land (Bai et al., 2008). In India, soil studies estimate that 79% of Jodhpur's land is affected by soil erosion, approximately 54% of which exceeds the default soil tolerance limit[67] of 11.2 tonnes/ha/year (Shyamapura et al., 2003). Chapter Three (Table 3.1) provides further details.

- **NRSC:** The NRSC use remote sensing data in their measurements of land degradation. Estimates are available for the wider state of Rajasthan (2011-13) and show that the area under 'desertification' covers around 63% of the Total Geographic Area (TGA) (GoI, 2013). A study by CAZRI (Moharana et al., 2016), uses NRSC's remote sensing data from 2003 and estimates that 84% of the region of western Rajasthan[68] is affected by degradation processes such as: (i) wind erosion in croplands and dunes/sandy areas (>76% of area affected); (ii) water erosion in croplands and scrublands (approx. 3%); (iii) salinisation of mostly croplands (approx. 2%); and (iv) vegetation degradation of mostly scrublands and forests (approx. 3%). The study identifies about 18% of the area as severely degraded and 66% as slight to moderately degraded. Only 16% of the area of Western Rajasthan is not affected by dryland degradation (ibid.).

The extent of degradation is also commonly measured through changes in land productivity (Reddy, 2003). While land productivity can be defined in many ways, it is often measured as a construct of agricultural outputs (Joshi et al., 1996; Kangalawe, 2012). As discussed in Chapter Three, the area under cultivation has increased significantly since the 1960s. Figure 5.1 illustrates the increasing area under *rabi* crops, especially of new water intensive crops such as cotton and vegetables since the year 2000. Crop productivity in Jodhpur has been driven by increased inputs to agriculture, in comparison with the low-input, low-yield agriculture of the past. However as evident in Figure 5.2, productivity of the key *kharif* (monsoon) crops of pearl millet (*bajra*), pulses, and sesame are variable, and in some years, productivity was almost zero. This can be explained by high monsoon variability; for instance, the severe drought of 2009-2010 led to below average yields. Figure 5.2 also shows that inter-annual variability, typically associated with *kharif* cropping, is also present in the productivity of Jodhpur's key irrigated *rabi* crops, although to a lesser extent.

[67] In India, a default tolerance limit value of 11.2 Mg ha^{-1} yr^{-1} is used, based on the Univeral Soil Loss Equation (USLE). It assumes a soil formation rate of 1 inch in 30 years to justify the default loss tolerance limit value of 11.2 Mg ha^{-1} yr^{-1}. It is calculated using erosivity factor, soil erodibility factor, topographic factor, cover and management factor, and conservation practice factor. (Bhattacharyya et al., 2008).There have been criticisms of this default loss tolerance limit used by the government, since it does not facilitate site specific conservation planning and prioritising areas for watershed management activities in India.

[68] Western Rajasthan includes the districts of Jodhpur, Jaisalmer, Barmer, Jalor and Bikaner.

Figure 5.1: Area under key *kharif* crops (left) and key *rabi* crops (right) in Jodhpur district (1966-2014) (in '000 Ha)

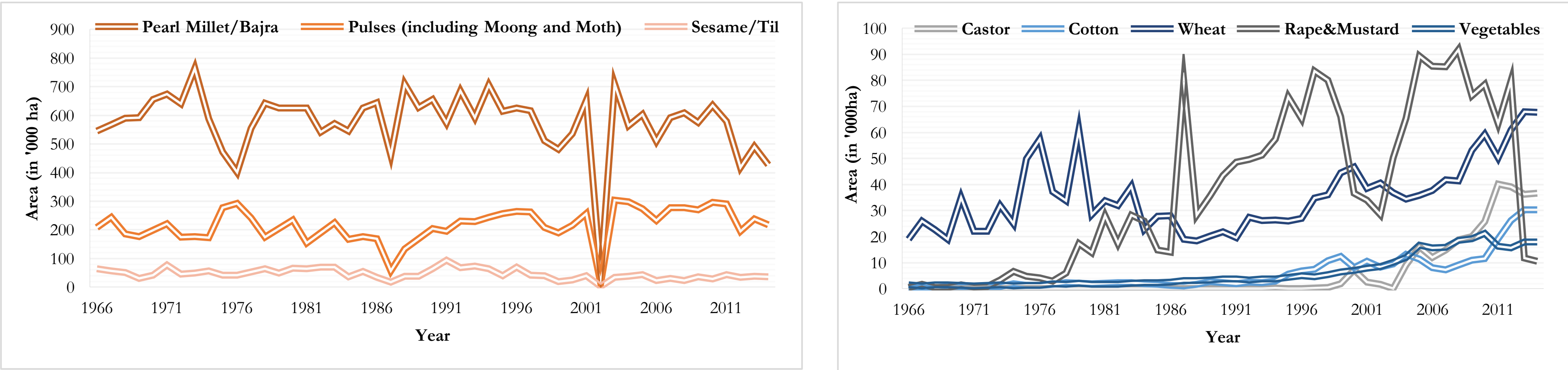
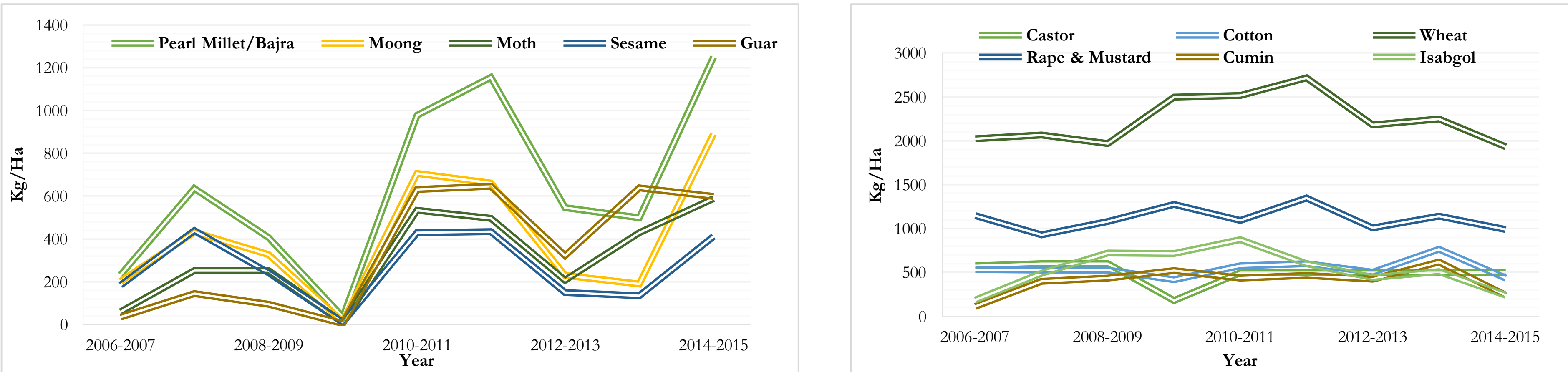


Figure 5.2: Productivity of key *kharif* crops (left) and key *rabi* crops (right) in Jodhpur district (2006-2015) (in Kg/Ha)



Source: Derived using data from GoR (2015) and NICRA (2014)

The extent of dryland degradation in Jodhpur is thus measured through different methods and all measurements show that degradation is significant in the region. The next section examines trends in key climatic variables of relevance to Jodhpur's land resources.

5.2 Observed trends in climate variability and climate change in Jodhpur

This section presents analysis conducted using Indian Meteorological Department (IMD) data from the two stations closest to the selected clusters: Shergarh station for Cluster I and Osian station for Cluster II. Since there are likely to be variations every few kilometres, rainfall and temperature events at individual stations are more relevant than district level averaged data. The analysis includes rainfall and temperature variables for the past 50 years, using daily IMD data from 1965-2015. In some instances, trends over 30 years are used (1985-2015).

Any changes in rainfall, temperature, and wind speeds will impact on land resources (Javed et al., 2012; Thomas, 2008a). Climatic parameters can reduce soil moisture, increase soil erosion, and affect plant development. Table 5.1, shows key climatic variables of relevance to the two clusters, collated using both secondary data and community perspectives.

Table 5.1: Impacts of key climatic parameters in the study area on dryland degradation

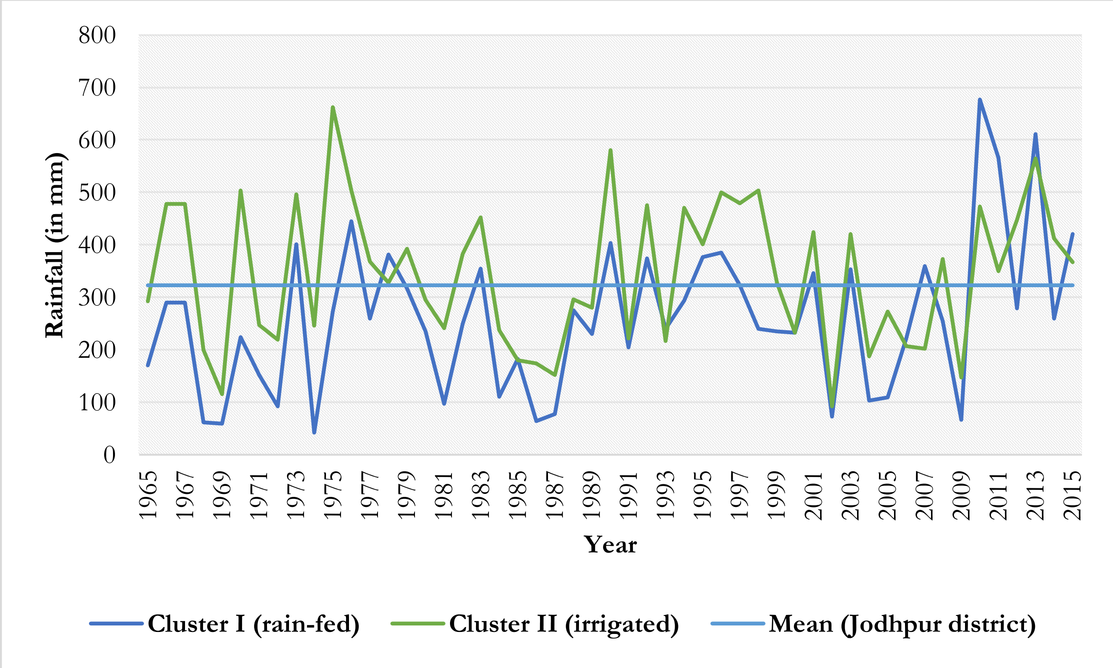
Climatic variables	Impact on land and crop development
Rainfall (low, variable, unseasonal)	Leads to soil erosion, water logging, and droughts. Provides conditions for development of pests and weeds. This in turn impacts negatively on the fragile parts of the plant, and affects pollination and pollinators.
Temperature - high	Leads to increased evapotranspiration, induced sterility in certain crops and survival of pests during hotter winters.
Temperature – low	Leads to morning dews on soil, destruction of cell structure (frost), soil structure, desiccation, and slow growth of certain crops.
Wind speeds	Leads to soil erosion, physical damage to plant structures (e.g. defoliation of shrub and trees), increased evapotranspiration, destruction of entire crops.

Source: Adapted from Das (2005)

General trends in rainfall over the past 50 years: Mean annual rainfall in Jodhpur is 323 mm/year (1965-2015). The CGWB (2013) in its analysis of long-term rainfall trends (1901-2012) highlights a 10% probability that annual rainfall will exceed 650 mm, and a 90% probability that annual rainfall will be more than 190 mm. The probability of receiving mean annual rainfall is 45% (ibid.). Rainy days are around 15 per year.

An analysis of rainfall trends since 1985 shows significant inter-annual variability with rainfall oscillating above and below the mean in both the clusters (see Figure 5.3). Average annual rainfall (1965-2015) in Shergarh (Cluster I) is 285 mm and in Osian (Cluster II) is 310 mm.

Figure 5.3: Annual rainfall trends in Cluster I and Cluster II (1965-2015) (in mm)



Source: Derived using data from IMD (1965-2015)

Authors such as Mortimore and Adams (2001), Thomas et al., (2007) and Usman and Reason (2004), have shown that mean annual rainfall is neither sufficient to capture the attributes of the impact on land users nor does it indicate the everyday climatic conditions faced by farmers on their fields. Seasonal, monthly, and weekly rainfall are more meaningful in analysing local trends and impacts. In the study area, more than 80% of the total annual rainfall is received during the southwest monsoon in the months of June, July, August and September (JJAS). JJAS rainfall occurs during the main cropping season of *kharif*. Table 5.2 summarises observed trends in annual rainfall between 1985 to 2015.

As indicated in Table 5.2, rainfall in June, July, and August in the majority of the years has been low: nine of the last 15 years in Cluster I and eight of the last 15 years in Cluster II have had below average rainfall during these months. Since 2010, the average September rainfall has increased markedly in both clusters (by around 196% in Cluster I and 146% in Cluster II). September is typically the beginning of the harvest season for the *kharif* crops. Unusually high rainfall in September leads to destruction of standing crops ready for harvest. The increase in September rainfall also explains the above average annual rainfall observed in the two clusters since 2010 (Figures 5.4 and 5.5). Notably, it shows that even seasonal rainfall estimates, when taken at a larger scale, may hide important variations in monthly rainfall.

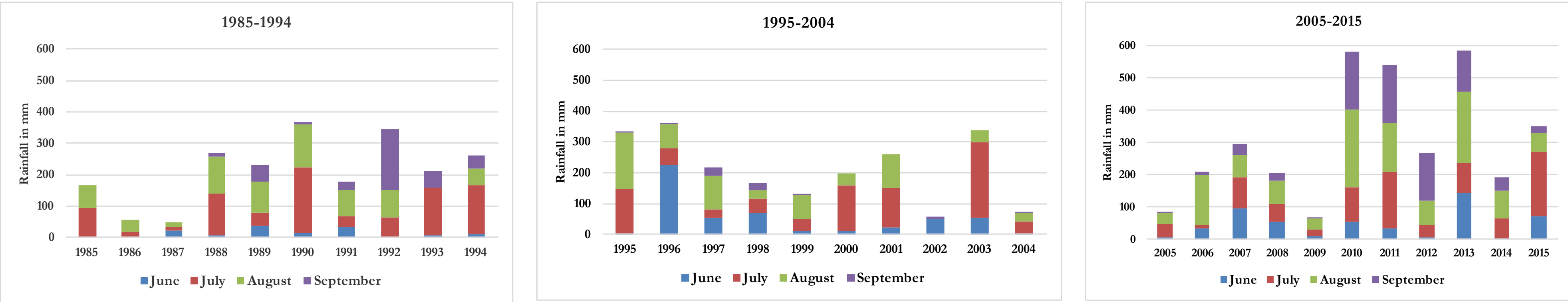
Table 5.2: Results of temporal analysis of rainfall for JJAS rainfall for both clusters (1985-2015)

	Cluster I (Shergarh meteorological station)		Cluster II (Osian meteorological station)	
	Average rain	**Key observations**	**Average rain**	**Key observations**
June	37.2mm	- 74% of the years have below average June rainfall - Mean June rainfall has increased to 51mm in the past 5 years, due to higher June rain in 2013.	39.6mm	- 58% of the years have below average June rainfall - Mean June rainfall has decreased to 23mm in the past 5 years
July	86.7mm	- 64% of years have below average July rainfall	104.8mm	- 58% of years have below average July rainfall
August	83.7mm	- 58% of years have below average August rainfall	80.0mm	- 48% of the years have below average august rainfall
September	39.5mm	- Since 2010, mean rainfall has increased to 115.5 mm	44.4mm	- Since 2010, mean rainfall has increased to 109.6 mm

Source: Derived using data from IMD (1965-2015)

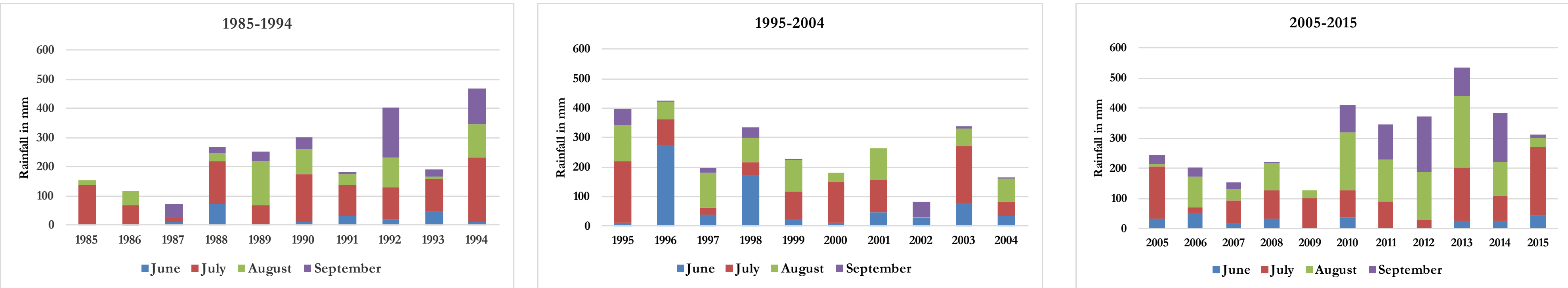
Figures 5.4 and 5.5 highlight the decadal variation in monthly JJAS rainfall in Shergarh and Osian between 1985-2015. The figures illustrate that in Cluster I, two of the last 11 years have had annual rainfall below 100 mm, while three of the last 11 years have had annual rainfall below or around 200 mm. In Cluster II the rainfall has been below 200 mm in three years since 2005. Further in June and September (sowing and harvest seasons) the rainfall varies from year to year in both clusters and this variability is a real challenge for farmers in making crucial decisions. For instance, low rainfall in June – an important month for the *kharif* sowing of millets and pulses – can significantly impact on crop yields, as discussed in Section 5.3.2.

Figure 5.4: Decadal JJAS rainfall in Cluster I – Shergarh station (1985-2015) (in mm)



Source: Derived using data from IMD (1965-2015)

Figure 5.5: Decadal JJAS rainfall in Cluster II – Osian station (1985-2015) (in mm)



Source: Derived using data from IMD (1965-2015)

Inter-annual rainfall variability: Analysis of rainfall extremes (highest and lowest rainfall); mean annual and JJAS rainfall; standard deviation of rainfall (dispersion of rainfall); and coefficient of variation (strength of rainfall variability) demonstrate the year-to-year unpredictability of rainfall. Table 5.3 summarises the results of the longer-term rainfall deviations.

Table 5.3: Rainfall variability over a 50-year period (1965-2015) for two stations

	Cluster I		Cluster II	
	Shergarh		**Osian**	
	Total annual	**JJAS**	**Total annual**	**JJAS**
Rainfall Range (extremes) (Mm)	42 – 676.5	37 – 584.5	94 - 615	73 – 579.4
Mean (Mm)	261.59	229.4	308.06	267.84
Standard Deviation	143.2	133.4	115.7	109.7
Coefficient of Variability	54%	58%	37%	40%

Source: Derived using data from IMD (1965-2015)

Both stations demonstrate an exceptionally high range in rainfall parameters. In Cluster I the rainfall varies from an annual low of 42 mm to a high of 676 mm. Both stations have rainfall with large standard deviations (SD), indicative of significant inter-annual and inter-seasonal variability. Coefficient of Variability (CV) - defined as the ratio of the standard deviation to the mean - is high as a consequence of the high SD and the absence of a trend in the mean. Shergarh station from Cluster I has higher variability, characterised by more extremes and a higher CV. While this is worrying, it is important to note that variability of rainfall is a characteristic of drylands (Krätli et al., 2015). Therefore, the same analysis is conducted for more recent years, to determine whether the trends in rainfall variability are increasing or decreasing.

Table 5.4 presents the results of the analysis of daily rainfall data for the past 15 years. Although mean annual and JJAS rainfall have increased since 2001, the variability of rainfall patterns has also increased when compared with the results in Table 5.3. The results show 'increasing variability' (higher SD and CV) during 2001-2015, when compared with 'normal variability' in the region (over 50 years).

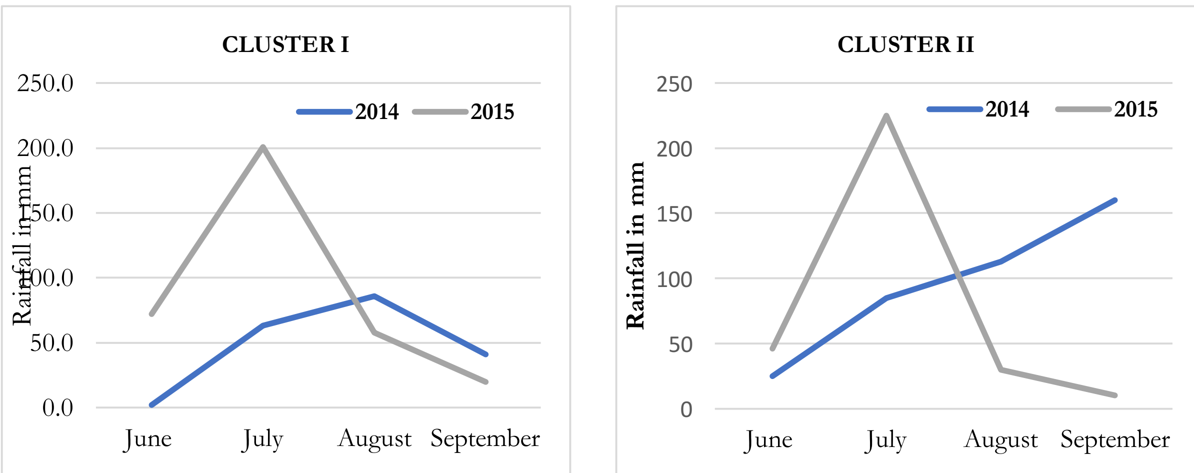
Table 5.4: Characteristics of rainfall variability over a 15-year period (2001-2015) for two stations

	Cluster I		Cluster II	
	Shergarh		**Osian**	
	Total	**JJAS**	**Total**	**JJAS**
Rainfall Range (extremes) mm	67 – 676.5	65 – 584.5	94 - 554	84.5 – 535
Mean mm	313.35	274.07	310.03	277.6
Standard Deviation	192.9	180.3	130.3	123.1
Coefficient of Variability	61%	65%	42%	44%

Source: Derived using data from IMD (2016)

Figure 5.6 demonstrates the growing intensity and spatial variability of rainfall patterns as experienced by farmers over two consecutive years (2014 and 2015). Monsoon rainfall in 2014 was well below average for June and July in both clusters. The bulk of the monsoon rains occurred during the end of August in Cluster I (86 mm) and in September in Cluster II (160 mm). Farmers reported that delayed and deficient rainfall followed by unseasonal rain and increased wind gusts in September, flattened the pearl millet crop that was ready for harvest and led to dryness in the pods of pulses (*mung* and *moth*). This resulted in a crop loss of 70-85% in 2014. The following year (2015) the monsoon patterns were reversed, with early rains in June, immediately followed by surplus rainfall in July, and below average rainfall in August (see Figure 5.6). The two clusters despite their proximity, show widely variant rainfall patterns especially in 2014, where rainfall in August and September was low in Cluster I but high in Cluster II. This further reinforces the argument that district level trends do not adequately reflect farmers' experiences.

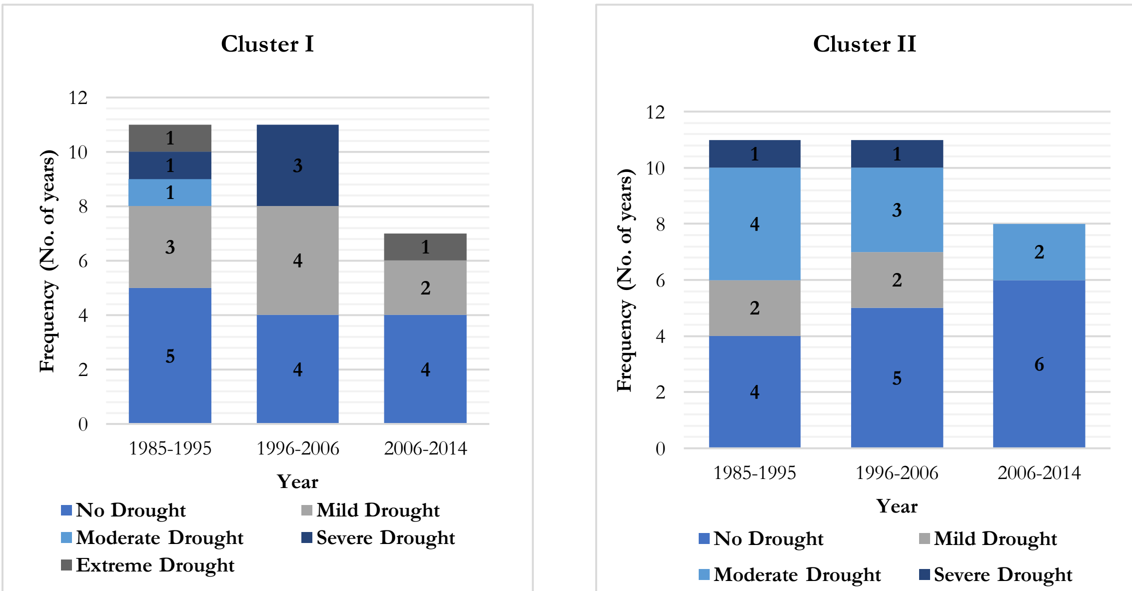
Figure 5.6: High rainfall variability over a two-year period (2014-2015) (in mm)



Source: Derived using data from IMD (2016)

Frequency of drought: Drought is a normal occurrence in this region and a moderate drought is expected every three years (Swain et al., 2012). The frequency and intensity of drought in the two clusters over a 30-year period (1985-2015) was analysed and the results are presented in Figure 5.7. Drought classifications (mild, moderate, severe, and extreme) are estimated according to the Government of India classifications of agricultural drought[69]. In both clusters, mild to severe droughts are common; for instance in Cluster I, droughts of varying categories have occurred in over 50% of the years every decade (since 1985). Mild droughts occur regularly and three severe droughts have occurred in Cluster I between 1996-2006. There have also been two extreme droughts, one in 1986 and another in 2009. In Cluster II moderate droughts occurred frequently and a severe drought has occurred once every decade.

Figure 5.7: Frequency of drought in the two clusters (1985-2014) (in no. of years)

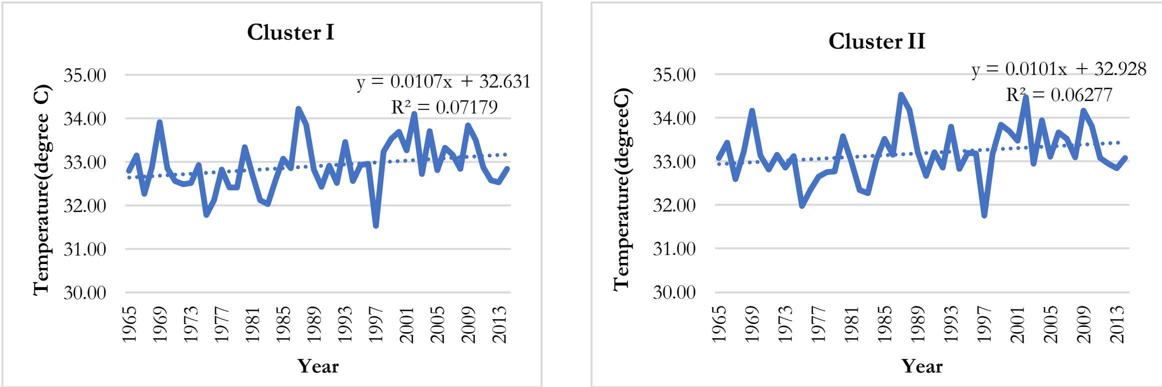


Source: Derived using data from IMD (2016)

Temperature patterns: Figures 5.8 and 5.9 show annual mean maximum and minimum temperatures for the two clusters. Annual average temperatures, both in the summer and winter, have increased in both clusters; the maximum and minimum average annual temperature increases are higher in Cluster I. Sharp increases in minimum temperatures are visible in both clusters, particularly since 2001. Temperature patterns in both clusters also demonstrate high inter-annual variability, indicative of the greater unpredictability of temperature patterns in the region. These variabilities lead to extremes of temperature which in turn cause heat waves and winter frost.

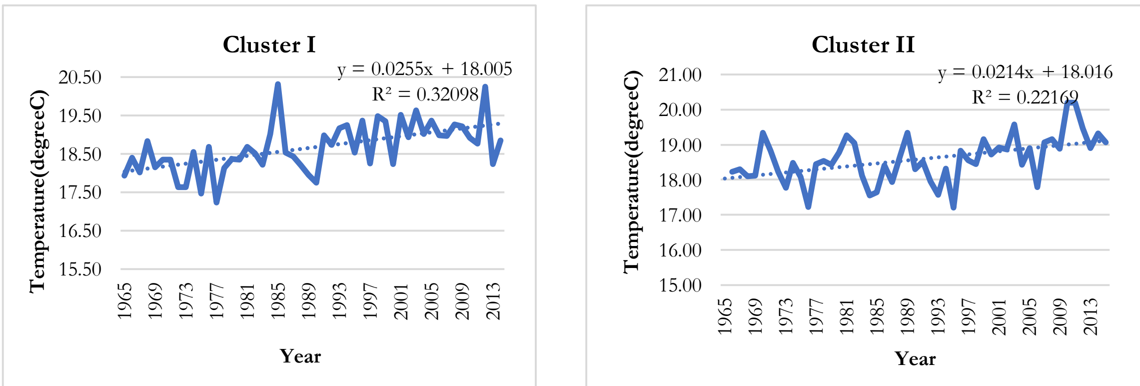
[69] GoI's agricultural drought classification provides estimates to measure the anomaly of aridity with respect to the long-term mean – 'Mild drought' is annual rainfall deficit of 1-25%;'Moderate drought' is a rainfall deficit of between 26-50%; 'Severe drought' is a deficit that exceeds 50%; 'Extreme drought' is a deficit of more than 75% (IMD, 2016)

Figure 5.8: Observed mean annual maximum temperature for Cluster I and II (1965-2014) (in degree C)



Source: Derived using data from IMD (2016)

Figure 5.9: Observed mean annual minimum temperature for Cluster I and II (1965-2014) (in degree C)



Source: Derived using data from IMD (2016)

Wind speeds: As discussed in Chapter Three, wind erosion is a primary contributor to dryland degradation in the arid regions of India. Despite this, there is insufficient data at the district or block level on wind speeds. A study by the Government of Rajasthan (2013) collated agro-climatic zone-wise wind speed data from different stations in Rajasthan. Mean wind speed in the arid-western plain (Ia) (where Jodhpur is located) is relatively high at 5.2 km/hour (see Table 5.5). For comparison, the highest wind speed averages in Rajasthan are in the north-western Plains (6.5 km/hour) and the lowest averages are in the transitional plain of the Luni Basin (3.8 km/hour). Maximum wind speeds occur in June, and are lowest in the months of November and December (GoR, 2013). Occasionally monsoon depressions originating in the Bay of Bengal, move from other directions and cause strong gusty winds and widespread rain before dissipating (Das, 2005).

Table 5.5: Mean annual wind speed statistics in the arid western zone (in km/hour)

Agro-climatic zone	Min.	Max.	Variation	Mean	CV
Arid-Western	3.3	8.1	4.8	5.2	0.24

Source: GoR (2013)

Summary of observed climate variability and climate change: Overall, the evidence from meteorological information points to: (i) increasing rainfall variability and unpredictability of sowing rain (in June), more so in recent years; (ii) increasing unseasonal rainfall, especially during harvest in September; (iii) rising temperatures in both summer and winter; and (iv) above average wind speeds. These climatic patterns interact closely with the state of land through its impact on soil moisture content, evapotranspiration, accelerated soil erosion, destruction of vegetation, and reduction in crop biomass productivity (especially root biomass).

Having established the status of land degradation and the trends in climatic variability and climate change using secondary data, it is now important to incorporate community perceptions of land degradation and climate risk. Community perceptions will help to clarify how the key variables identified at a broader scale impact on dryland degradation at a local level.

5.3 Community perspectives on climate risks and land degradation

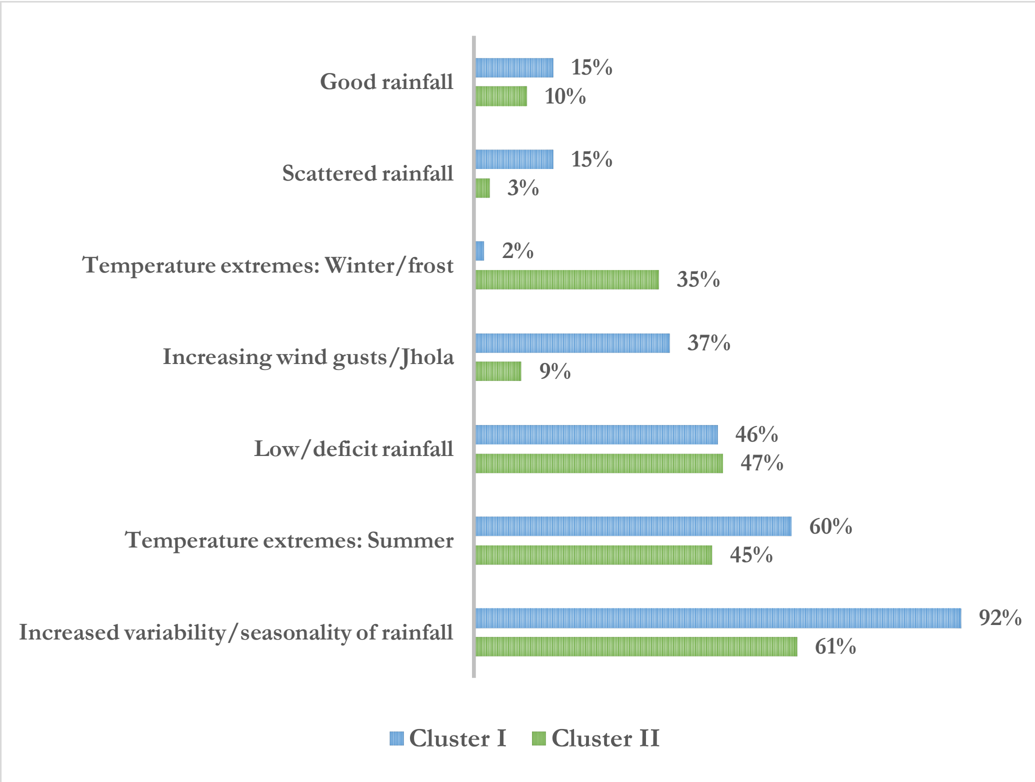
A few studies from sub-Saharan Africa (Kangalawe et al., 2008; Mertz et al., 2009; Simelton et al., 2013; Slegers, 2008) have analysed farmers' perspectives on climate change and their responses to risk in varying drylands. However, there are no peer-reviewed papers which analyse perceptions of communities on key climatic variables (such as rainfall variability) and the implications of these perceptions for land use and adaptation in the arid landscapes of India. This section therefore provides insights into the lesser known synergies and feedback effects between climate and land through the lens of community perspectives and motivations.

5.3.1 'The climate is changing': Community perceptions on climate variability and change

"The climate is changing; the monsoons are unreliable, it is too hot in the summer, too cold in the winter and the winds blow in too many different directions". (Source: I_FC2)

The above quote is indicative of the general perceptions of variability of key climatic variables observed by a majority of respondents in both clusters. Of the 163 households interviewed, 91% of the respondents noted that the general climate had been more variable and unpredictable during recent years. Figure 5.10 indicates the key climatic variables of significance as perceived by respondents in the two clusters.

Figure 5.10: Community perceptions on changes in key climatic parameters (in % households)*



*Communities were asked the question – Do you perceive any changes in your climate over the last 10-15 years (compared to past trends – maybe 20-30 years ago)? If yes, what key climatic parameters have changed e.g. rainfall, temperature? For each household interviewed, the respondent gave multiple responses (e.g. II_RB noted: increased variability, winter frost and scattered rainfall).

Particular observations of the key climatic variables as highlighted by respondents in the study villages are discussed below.

"Rainfall is variable and the seasonality is unpredictable": 92% of respondents in Cluster I and 61% of respondents in Cluster II thought that the general volatility in rainfall patterns was responsible for varying crop yields and general livelihood distress. The specific indicators used when citing seasonality in rainfall were as follows: timing of the first monsoon rain i.e. whether it comes late or early, and timing of rain during the growing season i.e. frequency and intensity of rain during critical phases of the cropping cycle (crop development and growth).

"We always expect low rain": Lower rainfall was highlighted by nearly half of the respondents in both the clusters (46% from Cluster I and 47% from Cluster II). The main concern for respondents relates to deficient rainfall during critical phases of crop development, rather than

low rainfall in general. During the household interviews, drought was rarely brought up as a major concern as respondent I_Kh11 explained:

"Drought is a centuries-old problem in this area; we expect drought once every 2 years, and therefore can try to cope with it; excess unseasonal rain, on the other hand, is of serious concern to us, since we do not know how to cope with it or predict it".

"God is now smiling on Rajasthan": Observations of a perceived increase in rainfall were reported by a small percentage of households (15% from Cluster I and 10% from Cluster II). They perceived improved rainfall patterns when compared with long-term trends. This was especially reported by older respondents, a number of whom referred to the increase in the number and diversity of trees in the area that was essentially a desert during their childhood. This was however typically followed up with a clarification that, while rainfall was higher, it was now even less predictable than during their childhood.

"The clouds are too small": Scattered rainfall was a concern brought up by 15% of respondents from Cluster I and 3% from Cluster II. Perceptions of rainfall varied significantly, at times within the same village. In the focus group discussions, a number of farmers described the distribution of rainfall as 'very scattered' and at times, within the same village, there was rain in only one small pocket. In the focus group discussions in Cluster I, the respondents perceived scattered rainfall to be a relatively recent trend, one that emerged in the early 2000s.

"Both summer and winter temperatures are extremes": Temperature patterns were universally reported to have increased in the summer. 60% of respondents from Cluster I and 45% from Cluster II highlighted a rise in summer temperatures. Increasingly frost-ridden winters were reported by 35% of the respondents in irrigated Cluster II, where problems of frost were attributed to cold snaps.

"Hawa (wind) ka Jhola (gusts) is consistently leading to crop losses of at least 50%": '*Jhola*' and *Pashchim Hawa* (north-westerly wind), which respondents perceived as 'increased wind gusts' or 'unexpected hot wind coming from different directions' was cited by 37% of respondents in Cluster I as leading to significant crop loss. In Cluster II, 9% of the respondents mentioned wind gusts as a significant factor. The more arid western blocks of Jodhpur district are home to shifting sand dunes and excessive wind erosion (Sinha et al., 1996), due to proximity to the desert. Farmers from Cluster I were therefore more exposed to these elements, and more likely to directly experience changes in wind direction and intensity.

It was noted during the field visit that while respondents perceived climate variability through differing lenses (e.g. impacts on sowing times, dryness of soil, agro-forestry, food security) there were many similarities in their experiences of living with climatic risks. This is evident in the discussion above; respondents used common terminology in communicating their perceptions and in general agreed about the key climatic parameters impacting on their land resources. It is important to highlight the indicators shaping respondents' perceptions of climate variability. The most commonly cited indicators of each climatic parameter are presented in Table 5.6.

Table 5.6: Indicators of climate variability and change as perceived by the respondents

Climate Variability theme		Respondents from both clusters (%)	Most commonly cited indicators shaping perceptions of key climate indicators
Rainfall	Unpredictable	77	- Timing of onset of the first rain - Higher risk in sowing times - Unexpected rain at critical phases of crop development such as during flowering, grain formation, ripening and harvesting leading to crop damage - Cloud cover at unexpected times leads to increased incidence of pests and diseases
	Deficit	47	- Below average rainfall during the monsoon - Good burst of initial rainfall followed by dry spells - Once crops are sown after the first rains, farmers mentioned the need for good rain after around 15-20 days to ensure good crop growth and yields.
	Scattered	9	- Smaller and patchier clouds - Poor spatial distribution of rainfall including isolated showers
	Surplus	13	- Increased number of trees - Greater diversity of trees including fruit trees such as Mango, Pomegranate and Lemon trees, which were not common in the area 20-30 years ago.
Temperature	Hotter summer	53	- Hot, scorching working environment - Stunted growth and poorer quality of hardy crops such as pearl millet, especially hybrid varieties that are not bred to tolerate intense heat.
	Colder snaps in winters	20	- Increasingly foggy and colder conditions, especially for winter (*Rabi*) crops - Greater incidence of frost in winter crops such as castor, mustard and cumin damaging leaf cells leading to lower yields
Wind	*Jhola* or wind gusts (north-westerly wind)	23	- Hot gusts of wind from different directions, usually in August/September, flattens standing crops which are ready for harvest - Dries up soil and roots
	High wind erosion*	NA	- Shifting sand dunes - New layers of sand deposits on the prepared land, leads to soil loss, dryness.

*wind erosion although not quantified in household interviews was mentioned as significant in all the group discussions.

Overall, the community perceptions of climate change are largely in line with meteorological evidence. Interacting with communities offers additional insight into the differential variability experienced by farmers. The key changes observed by communities with regard to climatic parameters are: (i) increased rainfall variability and unpredictability of sowing rain in June (Table 5.4 and Figures 5.5-5.7); (ii) decline in rainfall during key stages of cropping; and (iii) hotter summer months. In addition communities highlighted newer climatic patterns: frost in Cluster II and wind gusts in Cluster I. Greater incidences of wind gusts (*Jhola*) especially in the arid Cluster I, is a phenomenon on which no information currently exists. Scattered rainfall is also a relatively newer climatic pattern in the region and was mentioned by respondents in Cluster I. Scattered rainfall is typically reported at the field level and it is difficult to measure and monitor using climate data collated at broader scales. As evident in Figure 5.6, large variations can be observed between stations located in close proximity of each other, such as Shergarh and Osian.

Overall, respondents' key concerns about climate parameters almost always relate to its implications for the land resources they rely on (Table 5.6). The combination of climate risks and land degradation pose serious threats to agriculture and rural development. Having discussed perceptions of climate variability, the discussion now turns to community perceptions on dryland degradation.

5.3.2 "Our land is weak": Community perceptions on land degradation

As indicated earlier, there are critical gaps pertaining to both the understanding and measurement of dryland degradation in India. In this study, community perspectives are sought to gain clarity on the perceptions of dryland degradation at a household and community level.

The analysis in this section is conducted using data from the household interviews and only land that a particular household is responsible for (in terms of owning, leasing, or tilling) is included for discussion in this section[70]. In both clusters, this includes three main types of land use[71]:

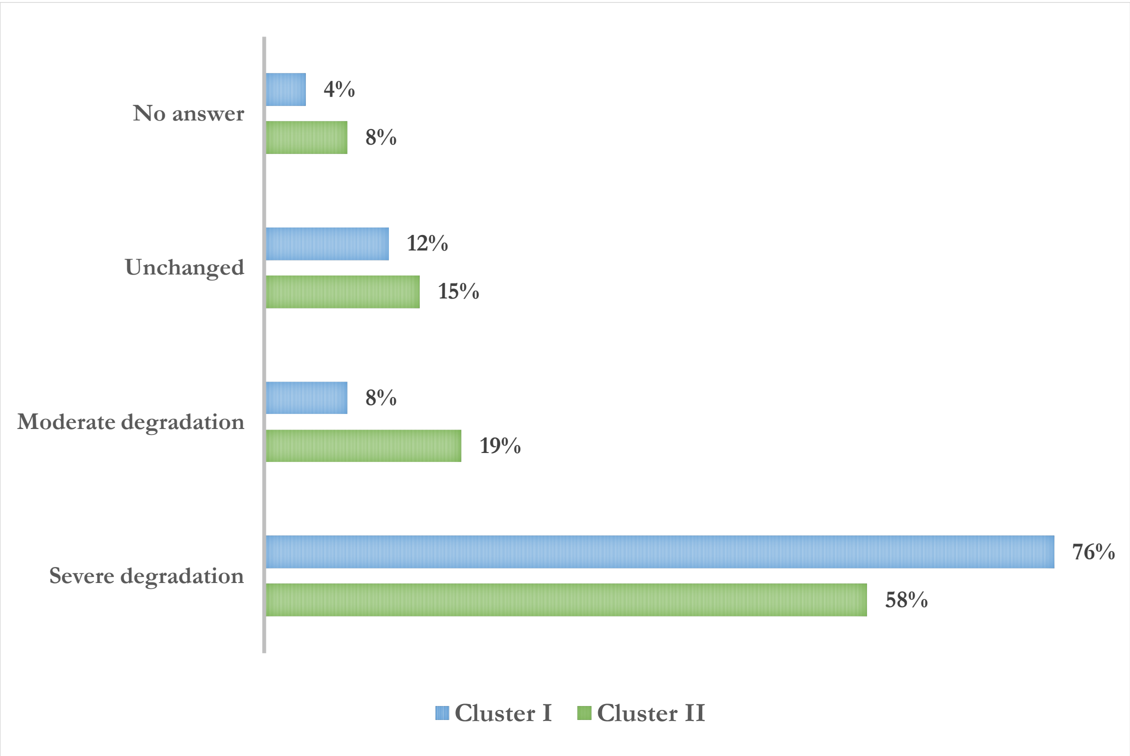
- Area currently cropped (net sown area): Total area currently under cropping (irrespective how many times the area is sown in a given year).
- Current fallow: Area under fallow in the given year.
- Long fallow (land under other fallow): Long fallow is a traditional crop rotation practice, where land is apportioned and deliberately not cropped for more than a year, and is left to replenish for up to five years. This practice has almost entirely

[70] Other lands not directly owned or tilled by the respondents including forest land, pasture land and barren and uncultivable land are not included for discussion in this section. They will be discussed in later sections.
[71] GoI descriptions of the varying land use categories are provided in Appendix I

disappeared in both clusters and respondents indicated that the area under long fallow is typically land that is almost entirely not suitable for cultivation due to degradation. The land would require significant amount of care to bring back to cultivation. As rainfall is low and organic manure is expensive (or unavailable in the quantities required), it is impractical to do this. Long fallows often have some low value trees and grass species on them, typically weeds, but they are still used as pasture land for household livestock.

While relating their views on the state of their land, respondents conveyed an appreciation that dryland degradation in the region is ubiquitous. Figure 5.11 shows household perceptions of land degradation. In the two clusters studied, 76% of respondents in Cluster I (rain-fed) and 58% of respondents in Cluster II (irrigated) stated that land quality had declined over the past 30 years and that degradation was severe. Moderate degradation was reported by 8% of respondents in Cluster I and 19% of respondents in Cluster II. Land quality was said to have remained unchanged according to 12% of respondents in Cluster I and 15% of respondents in Cluster II. Overall, 83% of respondents in Cluster I and 77% of respondents from Cluster II reported moderate to severe land degradation (Figure 5.11).

Figure 5.11: Community perceptions on the quality of their land (in % households)*



*Communities were asked the question - Can you say something about the differences in the quality of your land now in comparison with 20-30 years ago? Do you perceive your land to be severely degraded, moderately degraded or unchanged?

Respondents perceptions of ‘severe degradation’ relate to:

- *Weakness or reduced resilience of land*: Land quality has become extremely ‘weak’ and respondents perceived a significant reduction in its resilience (ability to bounce back after use of agricultural implements and/or external threats such as climate change and variability);
- *Declining crop yields*: Some respondents using crop productivity as an indication of land quality indicated their crop yields are declining every year as their land degrades; and
- *Lowered density of vegetation (on fallow land)*: Respondents particularly related to the inability of land to hold indigenous range grasses (such as *C. cilenis*) and the growth of weeds on fallow lands.

Respondents who identified ‘moderate degradation’ experienced the same shifts in degradation of land i.e. reduction in crop yields and non-availability of range grasses, but were of the view that the process is not as embedded and significant yet.

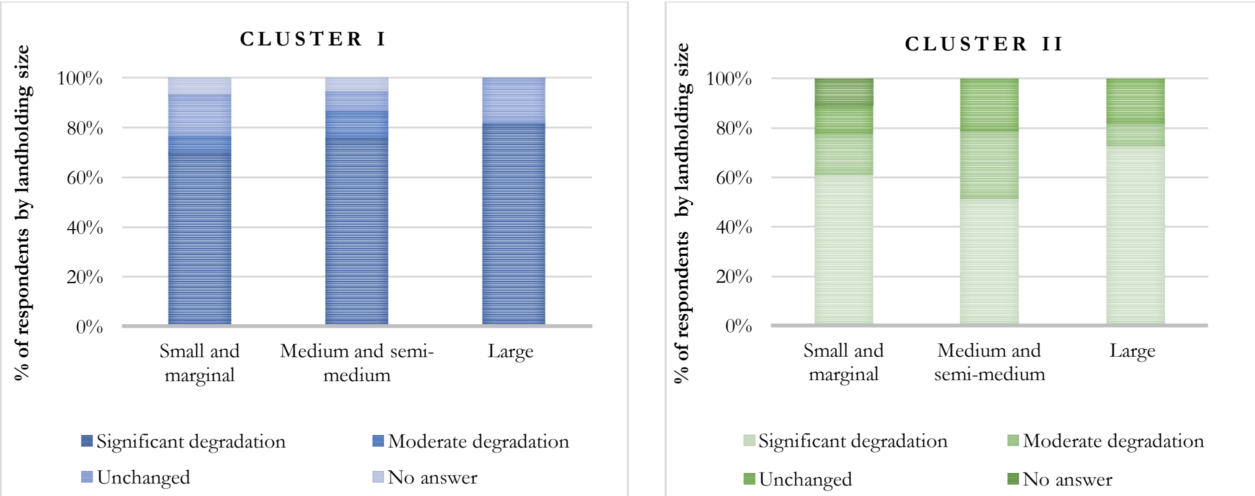
In addition to changes between the two clusters, perceptions of land degradation varied according to the social and economic context within which it was discussed. For example, Figure 5.12 classifies responses by landholding size. In Cluster I, ‘severe degradation’ was an observation that was collectively perceived by respondents across the landholding spectrum. Of the respondents interviewed in Cluster I, 82% of the large farmers (with landholding size >10 ha), 76% of semi-medium and medium farmers (with landholding size between 2-10 ha), and 70% of small and marginal farmers (with landholding size between 0-2 ha)[72] identified severe degradation. Of the respondents interviewed in Cluster II, 73% of large farmers, 44% of medium and semi-medium farmers, and 61% of small and marginal farmers identified ‘severe degradation’.

In both clusters, larger farmers were more likely to classify land as severely degraded. Discussions in the focus groups helped identify three likely reasons: (i) larger farmers typically invested heavily in the stock of their land, often relying solely on the yields from their land for income. They are thus more likely to perceive degradation to be ‘severe’ due to its significant implications for both their land and livelihoods; (ii) large irrigated farmers (such as in Cluster II) crop in at least two if not three cropping seasons every year. Primarily cash crops such as cotton, wheat, and vegetables are grown which require significant inputs, including synthetic fertilizers; (iii) poor quality groundwater in the *tehsil* of Osian (Section 3.3) and greater tillage of land was likely to negatively impact on the quality of their land.

[72] Landholding size in Rajasthan is typically divided into five categories – marginal (0-1ha), small (1-2ha), semi-medium (2-4ha), medium (4-10ha) and large (>10ha). In this section, for simplification in representation landholding size is apportioned based on three key classifications – marginal and small (0-2 ha); semi-medium and medium (2-10ha) and large (>10ha).

The analysis in Section 5.4 provides further insights, tracing key factors surrounding and exacerbating dryland degradation in both clusters.

Figure 5.12: Community perceptions by landholding size (Cluster I and Cluster II)



5.4 Community perceptions of critical factors driving degradation

While there are no consistent or universally accepted methods for tracking and tracing dryland degradation and its drivers (Kumar, 2011; Wilson et al., 2015), both secondary data and community perspectives show that land degradation is a serious and immediate threat to the livelihoods of the people depending on it, especially in the arid zones of Jodhpur. Respondents who cited moderate to severe degradation were asked about the parameters they commonly associate with land degradation. In both clusters, a combination of factors were cited as exacerbating degradation. For ease of discussion, the responses are first examined in two separate categories: (i) climatic factors (ii) land use and management factors; following this the interlinkages and feedback effects are explored in Section 5.5.

5.4.1 Climatic factors driving land degradation

Climatic factors are external or uncontrollable variables since they are factors or processes over which respondents have no control. Table 5.7 highlights the climatic factors cited by respondents as critical to dryland degradation[73].

In both clusters, low rainfall and unseasonal/excess rainfall were the most commonly cited climatic factors contributing to land degradation. Rainfall, especially its variability, seasonality, and extremes plays a vital role in increasing the risk of dryland degradation, due to its impacts on moisture regime and soil erosion (Nicholson et al., 1998; Puigdefábregas, 2005; Sivakumar

[73] Farmers cited multiple reasons for land degradation – for instance, II_Jh3 cited low rainfall, frost, and unseasonal rainfall as reasons for land degradation. Factors indicated in the table therefore do not add up to a 100.

& Stefanski, 2007). This impacts on areas such as Jodhpur where rainfall (as evidenced in Section 5.2 and 5.3.1) is highly concentrated in both time and space (a few weeks in JJAS), and results in runoff and high evaporation rates, which are further intensified by high temperature and radiation patterns.

Table 5.7: Climate related factors surrounding degradation: % respondents by cluster*

Climatic factors	Cluster I	Cluster II
Low rainfall	70%	84%
Unseasonal excess rainfall	69%	34%
Heat stress	4%	25%
Wind gusts	48%	10%
Frost	0	30%

*Respondents were asked the question - In your opinion, what are the key factors driving the degradation of land? Each respondent provided multiple climatic factors in their responses.

Other factors cited in Cluster I were wind gusts and to a lesser extent heat stress. Cluster I is located in proximity to the desert and wind gusts are more likely to have an impact on land quality, in comparison to Cluster II. Wind gusts cause quick evaporation, loss of plant tissue, and deposition of new sand on top-soil. Kar (2014c) in his study in Western Rajasthan noted that many semi-stabilised old dunes had become highly reactivated, advancing to lower areas. Respondents observed that the incidences of wind gusts had increased in recent years and when combined with deficit rainfall prior to harvest in the month of August/September, had damaged large portions of their standing crops. Incidences of wind gusts were particularly observed in the months of August/September and the main implication was '*scorching winds blowing in different directions dry up the soil and roots, and flatten standing crops*' (I_FC1).

Data on average yields and average loss of yields during key changes in climate was collated from the focus groups in Cluster I (I_FC1 and I_FC2) and are provided in Table 5.8. Pearl millet and pulses (mung and moth bean) are the primary monsoon crops in this cluster. Respondents indicated that in general *Jhola* often led to maximum loss of pearl millet (around 90% loss in yield), while unseasonal rainfall led to maximum loss of pulses (around 90% loss in yield).

Table 5.8: Impacts of climate variability on key *kharif* crop productivity in Cluster I*

Parameters of climate variability	Average yield of pearl millet	Average yield of pulses
Good/normal rainfall	5 q/ha	6 q/ha
Failure of early season rain (delay in sowing rain)	3 q/ha	5 q/ha
Unseasonal rainfall (prior to harvest)	1 q/ha	0.6 q/ha
***Jhola* (prior to harvest)**	0.5 q/ha	2 q/ha

*q = quintal (1q = 0.11 tonnes) Source: I_FC1

In Cluster II the responses were more varied, with heat stress, frost, and winds cited alongside key rainfall parameters. Here, the adoption of intensive irrigation practices in the recent past has led to greater reliance on groundwater and severe heat stress and frost are more likely to impact on irrigated land. This can be due to a number of reasons including: sensitivity of soil and crops to issues such as increased soil evaporation, accumulation of salts on the soil surface, cracking of clay soils above certain temperatures, and soil freezes in extra cold periods, that can dislodge soil leading to runoff (Sivakumar & Stefanski, 2007). Frost in particular is known to affect crops such as rapeseed and mustard, cumin and castor (Jangir & Singh, 2015), which are all grown in the winter season (*rabi*) on irrigated land in Cluster II. The impacts of heat stress and salinity on castor crop is visible in Picture 5.1 below.

Picture 5.1: Heat stressed castor crop wilting away in the village of *Chaupasani Charnan* (II_CC) (left) and in the winter, cracking of the soil (due to extreme cold temperature), salinity (white soil) and dryness in castor, are visible in the village of *Jheepasani* (II_Jh) (right)

Source: Author's own

In Cluster II, yields are typically higher than in Cluster I due to a greater utilisation of agricultural inputs, including greater use of urea and diammonium phosphate (DAP) fertilizers, and more tillage (see Table 5.9). Irrigation also acts as a buffer, lowering the impact of low or late rainfall in comparison to Cluster I. Farmers reported that they provide their *kharif* crops with irrigated water during droughts or periods with late rainfall. Average yields and average loss of yields during key changes in climate were collated from the focus groups and are provided in Table 5.9.

Table 5.9: Impacts of climate variability on *kharif* crop productivity in Cluster II

Parameters of climate variability	Yield of pearl millet	Yield of pulses
Good rainfall	10 q/ha	12 q/ha
Failure of early season rain (delay in sowing rain)	4-6 q/ha	10-15 q/ha
Unseasonal rainfall (prior to harvest)	3 q/ha	1-5 q/ha
***Jhola* (prior to harvest)**	0.5 q/ha	10-12 q/ha

q = quintal (1q = 0.11 tonnes) Source: II_FC1

Overall, the perceptions of farmers were that:

- Climate variability and climate change have a strong influence over land quality and land degradation, especially under rain-fed conditions;
- Low and variable rainfall, coupled with high temperatures and wind gusts are destabilising existing soil systems in both clusters;
- In Cluster II, *rabi* season cropping brings with it heightened exposure to additional climate stresses such as winter frost;
- Failure of early sowing rain (in June) and unseasonal rainfall (in September) has led to significant reductions in crop yields;
- Wind gusts have severely impacted on yields of pearl millet in Cluster I; although fewer farmers reported wind gusts in Cluster II. However, when strong winds occur farmers indicated they cause significant damage to the matured pearl millet crop.

The iterative relationship between climate and land degradation is further mediated by the impacts of land use and land management practices, such as selection of sowing times, ratio of inputs, and types of crop cultivated. The next section presents community perceptions of the key land use practices that contribute to dryland degradation.

5.4.2 Key land use management factors driving degradation

These are secondary or controllable variables, since respondents have some control over these factors. Table 5.10 presents the land and management factors contributing to dryland degradation, as reported by respondents.

In Cluster I, respondents associated land degradation with soil degradation due to continuous or over-cropping and tillage, and over-application of urea and DAP chemical fertilizers. Cropping in Cluster I is done largely in one season (*kharif*) and as mentioned, 98% respondents were practising rain-fed agriculture. In Cluster II, cropping is practiced in two seasons, and 81% of respondents relied on irrigation and sowed land over two and at times three seasons (*kharif*, *rabi* and *zaid*). The uptake and assimilation of modern agricultural practices coupled with an increased area under double cropping has lent itself to more varied responses to degradation, including groundwater-related stresses such as, the over-use of poor quality water, salinity, misuse of urea/DAP, and over-cropping and tillage.

Table 5.10: Land use and management factors contributing to land degradation by cluster*

	Cluster I	Cluster II
Over-cropping and tillage	20%	13%
Over-use of Urea/DAP	17%	44%
Salinity	1%	55%
Groundwater-related	-	70%

*Respondents were asked the question - What are the key factors driving the degradation of land?

Responses indicated that the excessive tillage of land without adequate organic manure application (from livestock), coupled with inadequate grass cover (due to deficit rainfall), and over-grazing of plant residues (due to fodder scarcity) had led to a decline in land quality. Respondents' views were in line with scientific studies on the impacts of tillage on land in the study area. Experiments conducted by CAZRI in Jodhpur found that during a dust-storm, tractor-ploughed sandy plains lost more than 3000 tonnes of soil per hectare while the sandy plains with 10–12% of vegetation cover (desert scrub) were subject to almost negligible erosion (Dhir et al., 1992; Kar et al., 2009). Similarly, Kar (2014b) traced the impact of deep tractor ploughing on the slopes of sand dunes in the district and reported that, degradation patterns were exacerbated by loosening of the naturally stabilised sand to a greater depth. Further, all vegetation was uprooted by tractors on the farm to stop competition for moisture between the cultivated crops, grass, weeds, shrubs, and trees (ibid.).

Respondents in Cluster II cited groundwater-led degradation and salinity as two separate problems. Groundwater availability and quality are in poor condition in the district. Research from the late 1990s warned of excessive use of groundwater in this area (Singh, 2002), but respondents, especially in Cluster II, while aware of the declining rates and quality of groundwater, continue to rely heavily on it, at times even during the monsoon cropping season. For instance, annual groundwater exploitation in Cluster I (Balesar block) is 147.9% (a net groundwater balance of -9.16mcm) and in Cluster II (Osian block) is 286.2% (a net groundwater balance of -129mcm) (CGWB, 2008)[74]. Many respondents in Cluster II noted that as they dug deeper and deeper every year, the quality of water was saltier and more brackish.

[74] Further information on the status of groundwater degradation in Jodhpur district is provided in Chapter Three.

The CGWB reports support the observation that the chemical quality of deeper groundwater has large variation with electrical conductance from 587 ms/cm at 250C to 31370 ms/cm at 250C (ibid.)[75]. Respondents often spoke about the government's 'dark zone' policy, where digging of new tubewells has been banned. However, no ban is currently imposed on those who have many deep tubewells already in use. The use of water is also unregulated. In the village of I_Ch, respondents reported that drinking water from local tanks and pond catchments (*Johads*), traditionally meant for livestock and domestic use, are being used for irrigation. The reasons for this will be discussed further in Chapters Six and Seven. The impacts of groundwater on the agricultural land is visible in Picture 5.2.

Picture 5.2: Visibly waterlogged (left) and saline soil (right) being prepared for *Rabi* sowing in November (2015) in the village of *Rampura Bhatiya (II_RB)*

Source: Author's own

A few respondents observed no changes or in a few cases, improvements in land quality. These respondents indicated that the application of an appropriate amount of organic manure (from livestock) was essential if deep ploughing of the land was to be continued so as to maintain the balance of nutrients in the soil. They stated that good land use practices which consider the suitability of crop to soil (shifting from wheat, cumin, chillies to carrot which requires less water), can help retain soil quality. Although analysis on the significance of farm location to the responses could not be conducted within the time frame of the field work, the perceived

75 Electrical conductivity (EC) is an important parameter in groundwater quality assessments for drinking and irrigation, since it is related to the concentration of charged particles in the water. The composition of mineral salts increases the electrical conductivity of groundwater.

improvement in the quality of their land could also be a result of the location of their farms (being in a low-lying area with deep soils or near a water source with better vegetation). In Cluster I, land quality was also associated with improved rainfall patterns and an abundance of tree diversity, especially around farm boundaries, which reduces the damage of wind erosion to land and crops. Studies from CAZRI demonstrate how silvi-pastoral systems have helped to reclaim alkaline soils in Rajasthan (Tewari et al., 2007).

Thus, cultivation practices such as deep ploughing, the use of poor quality groundwater for irrigation, and the increasing use of chemical fertilizers such as urea/DAP (overcompensating for deficiencies of nitrogen and phosphorous) in dryland soils have contributed to dryland degradation in the two clusters. In combination with the climatic factors identified in Section 4.5.1, conditions for degradation are enhanced.

5.5 Interactions between climate change, land use and land degradation

The links between climate change, land management practices, and land degradation are multi-dimensional and complex; community perspectives help to broaden our understanding of these interactions. In the previous section, the drivers of degradation were discussed under two broad groups: climatic factors and management factors. However, at the ground level, there are a multitude of factors that influence degradation, and some of these factors cannot neatly fit into categories such as 'climate' and 'management'. The field research revealed that there are likely to be many interlinkages between them. In aggregating responses from the household interviews, over 63% of respondents in Cluster I and 86% of respondents in Cluster II described a combination of climate and management factors as contributing to the degradation of their land.

Socio-ecological system interactions are typically conceptualised as neat and distinct blocks (Alessa et al., 2016), where the human and natural systems interact in a relatively hierarchical manner with simple and clear flows (Demeritt, 2009). There is little understanding of the complex interactions between climatic factors and management factors that operate and shape dryland agro-ecosystems. For instance in Jodhpur, the surface soil layer is markedly sandier than the sub layer, where the mean clay and silt content is higher. In such cases, a possible underlying causal mechanism could be the frequent preparatory ploughing which is carried out to remove unwanted vegetation. This in turn interacts with climatic factors such as strong winds, and erodes the soil surface layers. These varying levels of interactions have not been fully explained in research but were frequently brought up by respondents. The interlinkages between climate change, land management practices, and land degradation as narrated by the respondents are discussed below.

5.5.1 Greater pressure on sowing times

The sowing period was the single most reported factor when comparing differential crop productivity between households and between cropping seasons. The respondents reported that their decisions about sowing times are influenced by two critical factors: (i) unpredictability of 'sowing rain' including timing and magnitude of the first and second rains (farmers reported a crop loss of around 50% if rainfall is delayed by more than 15 days); and (ii) 'weakness', a term used by farmers to reflect the limited moisture holding capacity of degraded land; in previous decades, land was resilient and able to retain moisture for longer periods until the requisite amount of rain occurred. Soil scientists consider rainfall to be the most important erosion factor, either drying up soil or dislodging soil particles, making them susceptible to runoff (Puigdefábregas, 2005; Sivakumar & Stefanski, 2007). Respondent I_NN10 provided context to the vagaries brought on by increased rainfall variability.

"Previously, we expected drought every other year and knew how to cope with it. Now, rainfall is so variable and scattered that we feel we live in a new zone every year. I have to gauge whether to sow in June, July or August and it all depends on my luck. If I choose to sow in June after the first rain, and the second rain does not follow like it should, I will lose everything. On the other hand, if I wait for the second rain to sow, the rain may never come and I will lose all my input costs. Last year, I was lucky and sowed at the right time, but my neighbour was not so lucky".

As 'sowing rain' (typically refers to June rainfall) becomes more unpredictable, some cautious respondents choose to hold back sowing till as late as August, while some distressed farmers report preparing land and sowing multiple times until adequate rain comes. Frequent and multiple land preparation practices in turn exacerbate soil erosion from rainfall and wind.

5.5.2 Preference for high-yield variety seeds (HYV)

Rainfall variability has forced many respondents to shift from local varieties of crops to HYV. Local varieties of pearl millet, while hardy and well adapted to surviving under moisture stress and extreme heat, have a longer maturity period (70-80 days), making them a riskier option in times of intense rainfall variability. HYVs are short duration crops with a cropping cycle of only 45-50 days, which provides farmers with a shorter window within which to harvest their crops. However, in comparison to local seed varieties, HYV seeds are less tolerant to extreme temperatures. Further, some respondents revealed that some HYV seeds require ample fertilization to achieve their full potential. Due to the paucity of organic manure in the region (as livestock numbers have reduced), urea and DAP are applied in large doses for the HYV crops. These in turn contribute to dryland degradation.

An important trade-off for respondents is that heat stress eventually leads to poorer grain quality of HYV millets. Respondent I_DB9 stated:

The quality and taste of the pearl millet that results from the HYV seeds are poor in comparison to our local varieties. Our local variety seeds provide better taste and nutrition. We also cannot store the HYV pearl millet as it seems to 'disintegrate' quickly.

As the quality of grain declines, their storage capacities fall and they can no longer be stored for long periods and need to be either sold immediately or used for fodder. In Cluster I, traditional storage systems (*kothas*) (Section 3.4.1) are used by many to preserve grains for 2-5 years as an adaptation practice against drought and crop losses. Pearl millet constitutes approximately 80% of the local food and nutritional intake of the households in the region. For subsistence farmers, such as those in Cluster I, poorer quality of millets has threatened long-term food security. Respondents also reported that the use of HYV seeds has increased their dependency on the market, where seeds have to be purchased every season. This has placed them at the mercy of local shopkeepers, who at times provide low quality seeds or reserve the best HYV varieties for farmers who pay extra. Local seed varieties on the other hand are extracted from the previous seasons crop, and allow marginal and small farmers to remain self-reliant.

There is little research on the improvement of HYVs of pearl millet, due to its reputation as a subsistence orphan crop[76] (Varshney et al., 2012). More than 500 million people depend on pearl millet in parts of India and Africa (e.g. Nigeria, Mali), but research, agricultural training and extension continue to lag behind other crops, e.g. crops that offer larger-scale, market benefits (FAO, 2016; NRS, 1996).

5.5.3 Inadequacy in coping with newer climatic patterns (e.g. wind gusts)

'*Jhola*' or wind gusts and their interactions with land and agricultural systems are rarely included in research and adaptation planning. Meteorological evidence to trace patterns of wind gusts is also limited. Additionally, wind erosion, wind velocities, and gusts are terms that are used synonymously. Consequently, they receive very little attention in designing adaptation strategies. In the meantime, wind gusts are causing damage to both land quality and land productivity.

The respondents provided some unique insights into the linkages between wind gusts, use of HYV seeds, and crop losses. A key difference between local seeds and HYV of pearl millet is that HYVs typically have homogenous development patterns (and quicker development times), such that all plants mature at the same time. Increasing wind gusts, coupled with excess or unseasonal rainfall in September thus leads to a larger-impact destruction of standing crops.

[76] Orphan crops are those that are not traded internationally, and therefore breeding technology for these crops is lagging behind modern technology. They're typically grown in Africa, Asia, and/or South America and eaten as part of local diets.

Many respondents indicated that their entire *kharif* crop had been lost due to destruction/flattening during extreme wind gusts coupled with unseasonal rainfall.

Studies on wind erosion and increased wind velocities exist and agro-forestry is typically suggested as a measure against wind erosion (Stigter et al., 2002). However, respondents indicated that wind gusts came from different directions and typically at a time (September/October) when indigenous trees (such as *khejri*) in the region were lopped to meet food, fuel, and fodder needs. They do not therefore function as adequate barriers against the wind.

5.5.4 Need for multiple ploughing

A demonstration of the growing 'weakness' of the land was the increased frequency of preparatory tillage required before sowing. Respondents stated that previously a disc harrow (a farm equipment) was used to till the land once every 3-4 years, but they currently use it two to six times a year, even in the years of good rainfall. More frequent preparatory ploughing, loosens the soil and makes it more vulnerable to the impacts of wind erosion. The moisture holding capacity of the soil is also reduced by frequent tractor ploughing; it increases dryness of the soil, especially during the hot summer months when *kharif* crops are sown (June, July).

In Cluster I, farmers recognised that the practice of disking and harrowing of sandy soils (Picture 5.3), to reduce clod percentage in surface soils, encouraged erosion and led to surface crusting. They however linked the continued practice of multiple ploughing with growing rainfall variability. One of the main reasons for frequent ploughing, especially during *kharif*, was the unpredictability of 'sowing rain', where land was prepared multiple times in the same month, while waiting for rain. For most farmers hiring a tractor is expensive (around INR 350-500/hour[77]) and if possible, they would choose not to plough more than once per season. Respondent I_KB5 said in this regard, *"Waiting for rain for sowing bajra (millet) has become a game of taash (*card game like poker*)"*. Risk-averse farmers therefore chose to prepare the land as many times as it takes before the sowing rain arrives. As they identify, the alternative would mean no returns on farming for an entire year.

The creation of 'edaphic' (soil-related) droughts during otherwise 'normal' years due to land degradation has been cited elsewhere (e.g. Herrick et al., 2012: 283) although not linked directly with tillage. Land degradation exacerbates climate change-related water deficits that result from extreme temperatures and the consequent increase in evaporative demand. Jodhpur district is highly moisture deficient and has one of the highest evapotranspiration rates in Rajasthan (annual rate of >190-200 cm) (GoR, 2009).

[77] Equates to around 4-5 USD/hour

Picture 5.3: Tractor with disc harrow attached at the back. A disc harrow is used to reduce clod percentage in sandy soils. It however leads to increased surface crusting and moisture stress, exacerbating conditions for degradation

Source: Author's own

5.5.5 Groundwater extraction and salinity

Due to historically low rainfall, groundwater recharge is slower than the rate of extraction. In Cluster II, where irrigation is prominent, new tubewells are dug deeper every year to tap into groundwater reserves. Simultaneously, older tubewells are drying up and respondents in Cluster II reported large scale abandonment of existing tubewells (this will be discussed in Chapter Six). Problems of mineralisation and salinity have become more acute as groundwater levels decline. The application of saline and brackish water is exacerbating degradation.

5.5.6 Stubble mulching - Lower density of grass on cropland

Respondents recollected the greater presence of local grass species (*C. cilenis*) on cropland and fallow land in previous decades. The layer of grass on the soil acted as a natural control against wind erosion of the top soil. It was useful as fodder for livestock, and during tillage it was organic mulch for the soil (ploughed into the soil during tillage). Land degradation coupled with lower rainfall patterns and increased heat stress, has led to a loss of this source of fodder and fertilizer. Over-tillage and over-grazing on the land has further reduced the ability of the land to retain grass species. To replace the grass species, farmers started to leave crop residues of pearl millet on their field after harvest (millet stubble of around 30-40 cm in height). However, more recently, stubble mulching has been discontinued. Any crop residues are cleared and stall-fed to livestock after harvest and is thereby not available as organic mulch in the fields. This is largely driven by growing fodder scarcity in the villages together with poor quality and reduced access to community pasturelands. This has in turn led to an excessive reliance on fertilizers such as urea and DAP to compensate for the loss of nitrogen in the soil and exacerbated dryland degradation.

5.5.7 Imbalanced soil fertilization in arid lands

For fertilizers to be effective in increasing productivity, the soil needs to be adequately saturated with moisture through irrigation or rainwater (II_FC2). However, rainfall in the region is insufficient to adequately utilise the fertilizers applied, especially DAP, which is regularly used alongside urea in the study area. Irrigated water is also saline and is thus unsuitable to adequately supplement fertilizers. As indicated in Chapter Three (Table 3.2), the soil in Jodhpur is particularly deficient in Nitrogen (N), and availability of both Phosphorus (P) and Potassium (K) are also declining. In order to compensate for these deficiencies, an average irrigated farmer in Cluster II applies 190kg/ha of mixed Urea and DAP (50:50) to the soil during each cropping cycle, which is significantly higher than the average fertilizer consumption in India during 2012-13: 128 kg/ha (Sivagnanam, 2016). The levels of fertilizer use in these clusters are almost on par with the much more fertile plain zones of neighbouring Punjab, where 200-250 kg of chemical fertilizer (average) is applied per hectare (ibid.).

Smallholder farmers reported that while higher dosages of fertilizers increase the productivity of crops in the immediate cropping season, the same land has to be left fallow without cultivation for a minimum of two years to rejuvenate via rainwater. Leaving land fallow has been a traditional practice to maintain natural productivity of the soil. However, due to increasing fragmentation of landholdings and declining productivity, farmers are unable to leave their land fallow for such long periods. Additionally, as land continues to degrade, higher doses of fertilizers are required, leading to a vicious cycle of over-use and degradation.

5.5.8 Use of water intensive crops in the region

Land degradation coupled with climate variability has changed cropping patterns in the region. Respondents indicated that once dominant traditional crops such as red chilies, cumin, isabgol, papaya, do not grow as well, due to lowered capability of the land. New and unconventional crops such as cotton and vegetables are being taken up by farmers, especially in Cluster II. These crops are however water intensive; the groundwater is of poor quality and quantity, and as discussed earlier is likely to extend patterns of dryland degradation.

5.5.9 Summary of interactions and missing links

The findings thus far help draw out a few important but less well-known insights into the linkages between land use management, land degradation, and climate risks. Research in the arid zones of India consistently cite unsustainable land intensification by local farmers as the cause for degradation. In the analysis conducted thus far, clear evidence exists that climate risks are also important drivers of degradation; they impact on the land both directly and indirectly. Climate variables such as low rainfall, heat stress and wind gusts interact directly with land quality and exacerbate degradation. Further, the risks posed by increasingly variable climate, indirectly drive certain behaviours perpetuating degradation.

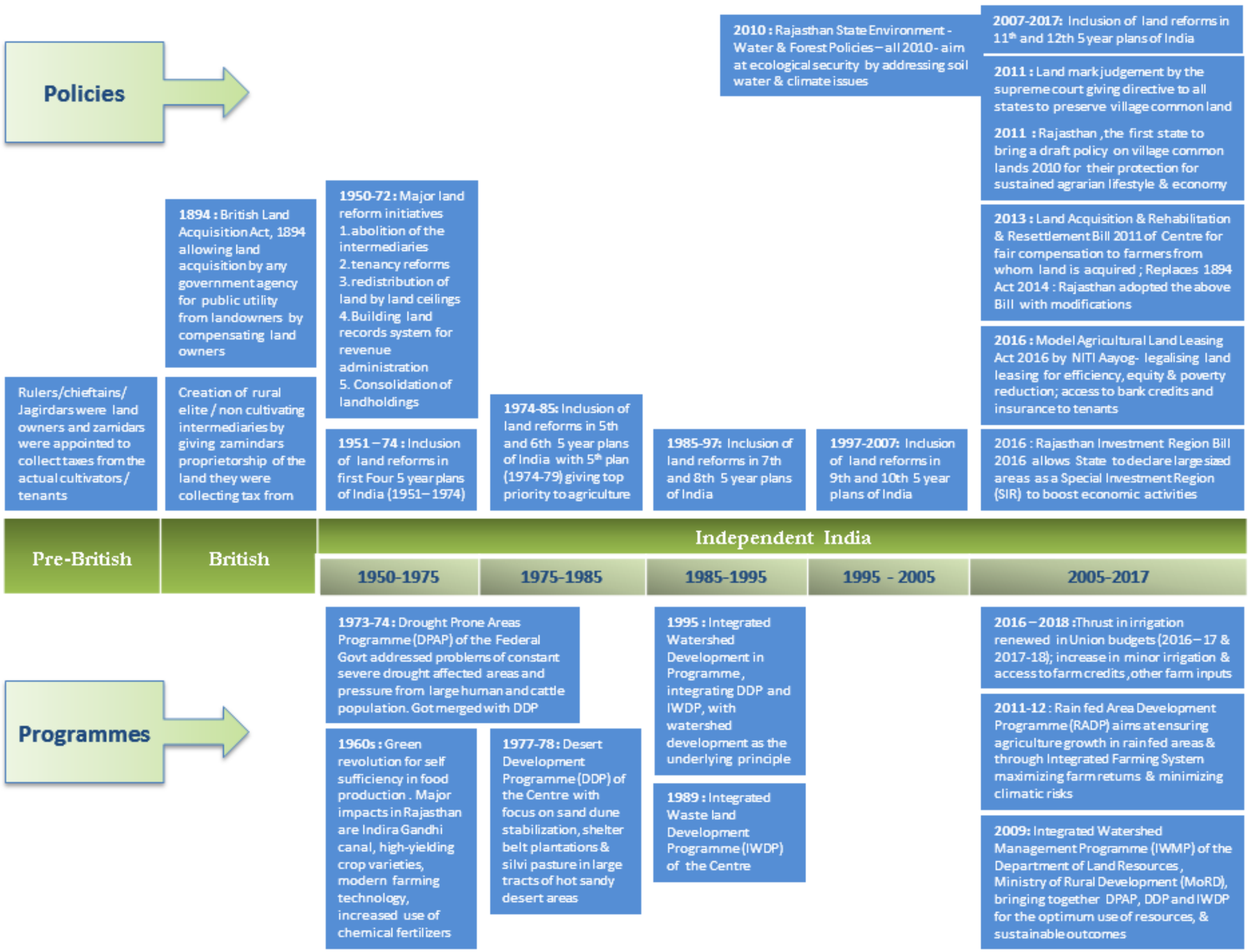
In addition to the linkages between climate change and land degradation, an underlying aspect governing land use and land management has not been discussed thus far. This is the role of policy and governance frameworks that underscore many of the land management strategies and responses to climate variability. Land policies that govern and manage the impacts on the land are an important link to better determine why and how land resources are used in the way they are.

5.6 The role of policy and governance

'We are not poor but the government makes us poor' – Respondent I_CH10

The impact that governance can have on managing land resources was understood by the many rulers of Rajasthan as evidenced by historical documents (Chapter Three). Policy frameworks are determined at a broader national and state level. Land use policy both directly and indirectly has the power to dictate how a particular household can use their cropland. The decentralised administrative structure of India's government and the key land policies and programmes of relevance to this research are discussed in Chapter Three (Section 3.2.2). A timeline of the most significant policies and programmes is provided in Figure 5.13.

Figure 5.13: Evolution of selected land policies and programmes in India



Source: Author's own

5.6.1 Land use policies

The primary objective of the land management programmes implemented during the formation of the state of Rajasthan in 1952 was to replace long-standing feudal agrarian structures (Jodha, 1982). However, in the complex feudal environment of post-independence India, land utilisation policies were executed without consideration of the actual features of the land. While keeping with the ideals of its new socialist state and in making the tillers of the land a priority, the actual land was forgotten, which in turn has made the tillers less resilient (Jodha, 1970; Robbins, 1998). For instance, very similar land utilisation policies were drawn up for the fertile, biodiversity-rich Aravalli range of mountains in eastern Rajasthan; and the hot dry western arid zone of Rajasthan. These policies exist to this day.

While land legislation did not specifically deal with the determination of the 'use intensity' of land, the tenancy reforms of the 1950s contained some provisions for the regulation of land use. Their approach was to stipulate that revenue officials should:

> *'Ensure a given piece of land is put to the same use to which it is included in the revenue records under which it was filed in the past'* (Jodha, 1982).

This has led to a vicious cycle of perpetuating maladjustments, where land regulation is a construct of revenue records and not its physical level of usability. Further, revenue officials were reported to have prohibited farmers from leaving large portions of their land fallow by making them liable to a fine if land was not put to a suitable use as per the previous year's revenue records (ibid.). This goes completely against the traditional land use management wisdom of arid zone farmers who, as discussed in Chapter Three, prefer to leave land fallow on alternate years to improve its fertility, a resilient practice.

5.6.2 Land distribution policies

In an attempt to abolish the zamindari system and promote equitable distribution of land, the land tenancy acts of Rajasthan (1950-72) put in place land ceilings[78] so that ex-*zamindars* could not control large landholdings within villages. This however led to fragmentations and sub-divisions where large landholders simply divided their land between their male heirs, to circumvent land reforms[79] (Ram et al., 1999). Respondent II_CC4 puts the legislation in perspective:

'My grandfather had 100 ha of land, which he divided up between his six sons after independence because he was worried about the tenancy laws. My father had around 16 ha for himself, which he had to divide between his three sons and his son-in-law (as dowry). I am left with about four ha of land, just enough to feed my small

[78] Land ceiling refers to a cap on the amount of land one person can hold.
[79] Transfer of land through inheritance is executed by equal sharing based on succession laws.

*family. I installed a tubewell and sow both kharif and rabi. My small parcel of land is getting increasingly white (*indicating salinity*) and degraded, but I continue to sow twice a year to feed my family".*

As indicated by this farmer the shrinkage of land holdings, initially done to evade the land ceiling act, complicated by subsequent population growth[80], is now tied to behaviours that have led to the perpetuation of land degradation. Farmers with smaller pieces of land are unable to continue the practice of land fallowing and mixed cropping, and instead are intensifying their land use practices.

Importantly, as indicated in Chapter Three (Table 3.6), large landholders in Rajasthan form only 7% of total landholdings but own 37% of the total land area (GoI, 2016). Therefore, despite tenancy laws in place post-independence, land distribution continues to be skewed in favour of ex-*zamindars*[81]. Mani (2016) in reviewing impacts of planning commission-led land reform reports that in looking to over-turn the British zamindari system, the Government of India made restrictive tenancy laws that have almost prohibited agricultural tenancy[82]. The tenancy laws left large landowners with little operational mobility over their land, and gave tenants complete control over any cultivation and revenue from the leased land. To evade these stringent tenancy laws, larger landholders preferred to lease land on unofficial and informal contracts, where they retained power over cultivation and the revenue from their land (Gupta, 2016). It appears that the informal agreements are skewed towards the landowner, leaving tenants highly insecure (in terms of retaining revenue). This is discussed further in Chapter Six where links are drawn between tenure insecurity and land degradation.

The NITI Ayog[83], a government body introduced in 2015, aims to review the land tenancy system. However, since its inception, there remains confusion on NITI's role. Its many critics have pointed to the lack of actual structural reform that is emphasised by the NITI (Pathak, 2015; Rao, 2015); it has been labelled as 'old wine in a new bottle' (Halder, 2016). New policies proposed by the NITI include the Model Agricultural Land Leasing Act 2016, which seeks to reform the old system of land leasing; it aims to provide flexibility within a lease, and allows for the terms and conditions to be mutually agreed between the owner and tenant (Mani, 2016). However, in keeping with the decentralised nature of India's governance, adoption of the policy is left to the state government. The new Land Leasing Act is yet to be adopted by the state government of Rajasthan.

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[80] While in many parts of the world, population growth could be a main reason for the sub-division of landholdings, in arid Rajasthan, the importance of the joint family has for long meant that sub-divisions were unwelcome and largely in response to the land ceiling policies (see Jodha, 1985; Ram et al., 1999)

[81] Large landholders in the villages visited are largely from families of ex-*zamindars* or *jagirdars* from the pre-British and British times. In these villages, it is very difficult for an ex-smallholder farmer or tenant to become a large landholder.

[82] Tenancy laws are detailed in Chapter Three where heritable and transferable rights are granted to tenants over zamindars

[83] NITI Ayog, as referenced in Chapter Three, has replaced India's Planning Commission. The aim of the NITI is to encourage participation of all levels of government and civil society in planning policy. The Planning Commission, formed in 1950 was considered to be too much of a top-down approach leading to formation of NITI

5.6.3 Pastureland policy

Pasturelands have not been discussed in detail thus far in this chapter due to the focus on dryland degradation on respondents' agricultural lands. Pasturelands traditionally formed a hub of activity, it was used by members of a village community for various purposes – "for their cattle to drink and bathe, for storing the harvested grain, for grazing, as a field for their children to play, threshing floor, carnivals, circuses, religious ceremonies, cart stands, graveyards etc."[84] (GoI, 2011). In a region where semi-pastoralism and pastoralism have been a main livelihood avenue for centuries, pasturelands used to be an important lifeline for village communities, particularly for grazing their livestock. While transferring the ownership and management of these pasture lands to the village *panchayat* in 1955, the central government placed no restriction on the use of these lands. Thus, almost all pasturelands (in the ten villages studied) have been converted to croplands, or are inundated with weeds due to neglect, or have been sold off to private industry[85]. This has forced many semi-pastoral and nomadic communities to shift to crop-based farming, and placed additional pressure on crop lands. The vignette below provides an example of a traditional nomadic *Rabari* household in Cluster II, where a majority of pasturelands have been converted to croplands due to a lack of institutional frameworks governing management.

Rabari farmer – Cluster II

II_Bh16; Age: 45; 8 household members (5 adult males, 2 adult women, and one male child, aged 10).

Babu belongs to the *Dewasi* or *Rabari* (translated as 'outsiders') tribe of people. They are traditional camel-herders and pastoral nomads who travel long distances on annual migration routes in search of new pastures to graze their animals. Around 50 years ago, Babu says his family became semi-nomadic, maintaining a base in the Bhawad village of Cluster I. From here the men (and male children) travelled for 6-8 months with their livestock (some assortment of camels, sheep, and goats), while the women stayed behind in small hamlets '*dhanis*' situated outside the village where they managed the land and livestock. The *dhani* typically includes 5-10 families of the same caste, who help each other with farming and familial duties. They eat together, collect fruits, and draw water together; sell wool, clarified butter, and jointly manage all land and livelihood matters. In the past Babu's family owned 15-20 camels, and about 500 sheep and goats. Even 10 years ago, his family had about 200 sheep and goats. They sold all their camels 30 years ago since the advent of roads reduced the value of camels as a means of transport.

[84] Supreme Court of India, Civil Appeal No.1132/2011 @ SLP (C) No.3109/2011
[85] Further details provided in Chapter Six.

Over the past 6-7 years, the advent of tubewells in this area has led to many *Gauchars* (protected pasture lands) being converted to cropland and attempts to leave sheep and goats to graze has led to significant disputes in the community. He therefore settled permanently in the village, sold all his sheep and goats, and bought three cows to meet daily dairy requirements (Picture 5.4). His family had to move into the main village, from their traditional *dhani*. Their large joint family of 30-25 people is now split; as in the village center there are only small houses with limited space. He now leases irrigated land from large landholders, where he receives only 25% of any income. In the leased land they grow carrots, wheat, cotton and onion. While initially he had some success in selling his produce in the market, poor land quality and insufficient groundwater are now decreasing the yields of all major crops, and in year 2014-15 he only sowed the *kharif* crop of pearl millet for subsistence.

Picture 5.4: Present day pastoral nomads travelling through the Thar desert. Here, they can be seen preparing *mawa* (a type of cheese which they sell as they travel) (left), while their animals graze nearby (right). Many nomadic tribes are now moving to sedentary livelihoods

Source: Author's own

Recently, the magnitude of the problem has increased with over-crowding in village centres (especially in Cluster II). The lack of pasturelands has also led to large numbers of livestock roaming free through the villages searching for fodder. Livestock trample on cropland and cause the soil to loosen and also destroy many crops.

Trade-offs are also visible with biodiversity conservation policies in the region. The Thar desert of Rajasthan has a rich array of fauna including the Indian gazelle (*Gazella bennetti*), Blackbuck (*Antelope cervicapra*) and Nilgai (*Boselaphus tragocamelus*). Concerns regarding their extinction due to poaching, habitat destruction, escalation of feral cows (due to loss of CPRs), have led to significant policy changes in the last decade, and the government has called for strong enforcement of the Wildlife Protection Act (Dookia et al., 2013). While these animals were difficult to spot even five years ago, a walk through any of the villages in western Jodhpur will now include multiple sightings of these animals. These have however led to problems for farmers, as crops are destroyed and soil compaction affected by trampling of Blackbucks and Nilgai in particular.

Land use policies have thus resulted in a loss of traditional sacred *Gauchars* (which offered religious significance), loss of grazing land which in turn has led to a change in the composition of livestock and a loss of organic manure (as livestock numbers decrease). Further, due to a loss of CPRs, livestock are now largely stall fed with grass and straw from cropland. This has in turn led to a loss of critical grass species or crop residues which are crucial for the maintenance of soil fertility (discussed in Section 5.5.6).

These growing concerns have led the Rajasthan state government to draft a policy on management of CPRs. Rajasthan is the first state in India to take a step toward reforming the old CPR policies. Following the National Policy for Common Property Resource Lands (Common Lands) 2002 and a landmark judgement by the supreme court of India (2002), the Draft Common Lands Policy 2010 of Rajasthan aimed to ensure that the land rights for CPRs are transferred back to the hands of the village community, with adequate monitoring by the state government and to ensure community land is not being encroached upon by the PRIs (GoR, 2010). As of 2017, the policy is still at draft stage.

5.6.4 Recent union budgets and the renewed thrust on irrigation

As agriculture continues to be an important sector in India's economy, irrigation remains a top priority in reforming agrarian landscapes and to help farmers cope with drought. Some of the recent policies aim for the sustainable use of resources. For instance a dedicated micro-irrigation fund to achieve, 'per drop, more crop' offers subsidies for investments in irrigation technologies, such as drip irrigation, that promote more efficient use of groundwater[86]. The government also continues to offer large subsidies for chemical fertilizers such as urea. The

[86] Micro-irrigation technologies, such as drip irrigation, carry only desired amounts of water, direct to the root zone of the plant, drop by drop. The aim is to reduce wastage of water. They are however not suitable for all crops and climates.

domestic production cost of urea is around 300 USD per tonne; farmers get it at a highly subsidised rate (less than 90 USD) (GoI, 2017)[87].

Upon closer inspection, while purporting to be farmer and conservation oriented, the entire emphasis is on augmenting irrigation coverage through massive investments. A blanket policy on irrigation is directly in opposition to sustainable land management in arid Rajasthan.

Many examples of changing social livelihoods are observed in both clusters (such as the *Rabari* farmer in Cluster II), as a result of such irrigation focussed policies. Traditional pastoralists, craftsmen, money-lenders, traders and religious practitioners are all now involved in agriculture as a main source of livelihood. These shifts to agriculture are led by opportunities now present in agriculture due to a shift to high input, high output agriculture, prompted by government policies and subsidies. Others have been driven from their traditional livelihoods and skill-sets (e.g. potters, skilled weavers) due to the lack of support from local institutions. This has led to an increased dependence on agriculture, and places excessive pressure on already fragile land and water resources. One of the key drivers of dryland degradation has been the shift from a balanced traditional approach to resource-use and diverse livelihoods to one focussed on extraction of maximum benefit from the land.

The focus on increasing crop productivity from lands that are ill suited to intensive agriculture has led to a cycle of bad land use management decisions and contributed to degradation. In Chapter Seven, these issues are reviewed to provide suggestions for interventions that are sympathetic to the practices that support rather than undermine traditional diverse livelihoods.

5.7 Conclusions

Finding 1: Land quality in the region has declined, with a majority of respondents in both clusters reporting moderate to severe degradation of their land.

Respondents in both clusters identified land degradation as a serious and immediate concern to their livelihoods. Around 84% of respondents in Cluster I and 77% of respondents in Cluster II reported moderate to severe degradation of their cropland. Land degradation was defined by respondents as a function of 'weakness' or 'reduced resilience' of their land, together with poor quality and quantity of yields, and reduced biomass. Due to their reliance on rain-fed farming, climate variability was cited more often in Cluster I as the primary cause of degradation. In both clusters, the consensus was that a combination of climatic factors (unseasonal rainfall, low rainfall, wind gusts, high temperatures) and management factors (over-

[87] The Government of India reimburses the difference to fertiliser manufactures. Fertiliser subsidy in India is the third highest (after oil and food subsidies)

use of Urea/DAP, over-cropping, salinity and other groundwater-related issues) are contributing to degradation. In the household interviews, over 63% of respondents in Cluster I and 86% of respondents in Cluster II described a combination of climate and management factors as drivers of land degradation. Thus, at a ground-level, there are a multitude of factors that influence degradation.

Finding 2: Community perceptions and meteorological data reveal increasing climate variability and newer climatic patterns such as wind gusts, frost, and unseasonal rainfall in the region. Evidence highlights the inadequacy of state and district level mean annual rainfall in adequately translating climate variability felt by respondents on the field.

A comparison of meteorological climate data with community perspectives shows that community perspectives are a good indicator of climate variability and change. Results revealed that growing instability of climatic patterns was a key concern for farmers (see Table 5.3-5.4 and Figures 5.5-5.6). The intense variability faced by farmers in the region, over just a two-year period is illustrated in Figure 5.6 and shows the difficulty in understanding 'normal rainfall' and the inadequacy of using mean annual rainfall, especially at a district level, to demonstrate trends as 'increasing' or 'decreasing' in the area. Further, newer climatic patterns and variables were described by respondents: (i) wind gusts (*Jhola*), where wind blowing in different directions dries soil, roots and flattens standing crops that are ready for harvest. Farmers explained that *Jhola* can be disastrous when combined with unseasonal rainfall, prior to harvest in the month of August/September. There are few scientific articles about wind gusts and its implications for crop productivity or meteorological evidence to trace the pattern; (ii) sudden and unexpected cold spells and frost impact on the soil and on *rabi* crops such as castor, cumin, mustard and vegetables, all of which wilt in these conditions. Farmers reported that this is a relatively new problem in the area and they are yet to devise adequate responses.

Finding 3: Communities perceive and provide unique evidence of the linkages between climate change, land management practices and land degradation in Jodhpur

The linkages between climate change, land management practices and land degradation are multi-dimensional, complex, and inter-twined as has been recognised by a majority of dryland researchers. The UNCCD (2015) highlights a key gap that exists in the identification of these complicated linkages at a local-level. Communities were able to broaden the knowledge of these linkages through the provision of unique evidence.

For instance, in drylands literature, frequent ploughing is associated with farmers' 'greed' for better yields (Kar 2014). However, farmers reported that frequent preparatory ploughing was instead due to the variable rainfall (sowing rain), where risk-averse farmers plough and prepare the land many times while waiting for the 'sowing rain'. Similarly, newer climatic patterns such as wind gusts, are changing the way previously successful HYV seeds of pearl millet (*Bajra*), grow and develop.

A combination of land degradation, lower rainfall patterns, increased heat stress and government policy for CPRs, has led to loss of local grass species (i.e. *C. cilenais*), which was a primary source of fodder and organic fertilizer. To replace this lost grass species, farmers have resorted to using synthetic fertilizers to make up for lost Nitrogen and Phosphorous in the soil. The over-application of Urea and DAP without adequate moisture (rainfall) has in turn led to an exacerbation of dryland degradation. Similarly, the lack of moisture in the soil, has led to over-exploitation of dwindling groundwater reserves with increasing salinity and waterlogging on the fields.

Upon reflection, it is evident that while over-use of synthetic fertilizers and intensification of land use and groundwater-based irrigation are important drivers of land degradation, this is only one part of the bigger picture of the dynamics surrounding dryland degradation in Jodhpur.

Finding 4: The significance of context in understanding dryland degradation and its interactions with socio-ecological systems is paramount. Adaptation and uniform strategies at a national, state or even district level may not be suitable.

In addition to temporal dynamics, spatial dynamics and variability need to be considered. The two clusters examined in this study are approximately 45 kms apart, and reveal two different stories. While respondents in both locations have concerns about land degradation and climatic change, the values they place on their land are different and thus their views on the factors contributing to degradation vary. Communities in Cluster I are relatively separate from the market; they do not depend as much on the market to either sell or purchase agricultural products. Thus, reliance on traditional staple adaptation practices, such as leaving land fallow, alternative cropping patterns, mixed cropping, traditional water-harvesting practices and systems (i.e. *khadins*, *johads*), and earthenware-based grain storage systems are still utilised. In contrast, such practices are almost absent in Cluster II, where closer links to markets, reliance on groundwater extraction and utilisation, and more intensive farming systems have precipitated a lock-in that does not enable continuation of traditional practices. The temporal and spatial variability is a good indication that, while climate risks and land degradation are inextricably linked in dryland agro-ecosystems, parameters of significance to both people and farming systems can vary based on endogenous factors such as communities' social, cultural, and institutional sensitivities, and their capacity to cope. There is a strong need to incorporate these contextual factors which contribute to land use management decisions into adaptation strategies. These factors are addressed in Chapter Six.

Thus far the focus has been on understanding the processes surrounding dryland degradation at a local level. The analysis in this chapter has shown that communities in Jodhpur are experiencing shifts in their land which is indicative of severe degradation. They are observing increasing variability of their climate and newer climatic patterns, exposing the land to additional stresses. Governmental policies are not conducive to maintaining traditional agricultural practices, instead they perpetuate behaviours of unsustainable intensification.

In looking back at the conceptual framework in Chapter Four, this chapter has focussed on the externalities potentially impacting on a system (hazards of climate, dryland degradation and policy changes) and linkages between these externalities and the region's agriculture and livelihoods. The next chapter focusses on the prevailing socio-ecological vulnerabilities embedded within these communities and the role played by vulnerability in mediating the linkages.

6. Assessing Vulnerability for Dryland Agro-ecosystems

This chapter presents an assessment of vulnerability for dryland agro-ecosystems, from concept to application. Global vulnerability assessments provide an overview of the generic processes that relate socio-ecological systems to external hazards (Adger, 2006; Brooks et al., 2005; Sietz, 2011). Regional conditions are only covered to a certain extent and only in regions where the information is readily available (Sietz, 2014). As discussed earlier in this thesis, data on socio-ecological system dynamics in drylands is limited. Thus the focus on dryland agro-ecosystems is often lost in vulnerability assessments conducted at larger scales (Sallu et al., 2010; Sietz, 2014). Consequently, adaption planning is limited by a poor understanding of the prevailing socio-ecological vulnerability of drylands. Dryland scholars have pointed out that regional and local heterogeneity needs to be better reflected, calling for research to develop viable vulnerability frameworks for specific drylands. Vulnerability is however a concept that has proven difficult to operationalise and assess with consensus, especially in drylands.

This chapter aims at improving the capacity to better reflect the local and regional heterogeneity present within drylands. The analysis in this chapter addresses research question two: **What are the key elements to be included in a framework of drylands vulnerability, that helps gain insights into the drivers of vulnerability and their interactions with the drivers of land use and land degradation?**

As mentioned in Chapter Four, vulnerability provides an interdisciplinary framework within which to integrate the biophysical and social system states, and the various external stresses and hazards they are exposed to. This chapter demonstrates an innovative methodology by honing current global conceptualisations of vulnerability into a specific framework for drylands vulnerability using local knowledge. Taking the case of the arid drylands in the district of Jodhpur, the methodology seeks to use a traditional index-based approach to vulnerability and enhances the results of the index using primary qualitative information based on community knowledge and experience. By better recognising local and regional heterogeneity, the analysis provides new insights into the interlinkages between land use, land degradation and socio-economic vulnerabilities.

The chapter is structured along the following research objectives:

- Section 6.1 introduces key concepts and approaches used for the vulnerability analysis, and emphasises the benefits of using 'endogenous vulnerability' to frame the assessment;
- Section 6.2 presents the results of the agriculture and livelihoods vulnerability index, including the rationale for the selection of criteria and indicators, assignation of

weights, and the final index values for households, villages, and the two clusters. The index helps to identify vulnerable sections of the population and drivers of their vulnerability;

- Section 6.3 summarises the key strengths and weaknesses of using a composite index (as developed and used in the majority of global vulnerability research) for arid Jodhpur;
- Section 6.4 expands the vulnerability assessment to include nuanced qualitative perspectives on the key drivers of vulnerability. The refined framework proposes a focus on three simple yet oft-neglected concepts, that are tailored to drylands: (i) Community-based interpretations of ecological and social thresholds: taking stock of the resilience of land and its related resources and societies; (ii) Lack of 'reliable' or 'true' access to resources and support institutions: focussing less on presence of assets and income, and more on the 'reliability' of access to resources and support services; and (iii) Sustainability of adaptive capacities: the ability of existing adaptive capacities to sufficiently mediate current risks without impacting on future resilience; and
- Section 6.5 summarises key findings of the vulnerability analysis.

6.1 Framing endogenous vulnerability for drylands

A majority of the worlds' drylands and communities that live in drylands are inherently vulnerable, due to their marginality, geomorphology, climate variability, and slow developmental patterns (Geest & Dietz, 2004; Robinson et al., 2015; UNDP, 2013). The Millennium Ecosystem Assessment (2005) highlighted that drylands, especially those in the transition between semi-arid and arid, such as the drylands of Jodhpur, are expected to become even more vulnerable in the coming years (Safriel & Adeel, 2005). As highlighted in Chapter Two, while vulnerability assessments have been used for several decades and streams of research, their use within drylands, especially the arid drylands, have been limited at best. One of the key problems facing vulnerability assessments in these regions has been the prevailing confusions regarding the various epistemological roots of vulnerability and how to apply vulnerability concepts (sensitivity and adaptive capacity) within the context of the complicated and dynamic nature of dryland agro-ecosystems. The challenge therefore lies in the development of a suitable framework that reflects the vulnerability of unique, fragile, and dynamic dryland agro-ecosystems, while ensuring that field level complexities and uncertainties are well captured in the assessment.

This analysis aims to contribute to a growing body of empirical work that employs elements of qualitative and quantitative methods to explore the social, cultural, ecological, political, and economic aspects of vulnerability in dryland agro-ecosystems (e.g. Fraser et al., 2010; Sietz, 2011; Sietz et al., 2017). Most studies are set in the drylands of Africa and the following approach places these issues within the context of the marginalised arid drylands of India.

6.1.1. Theory and concepts

The evolution of vulnerability thinking over the years is detailed in Chapter Two, from its origins in the theory of entitlements to its current position, rooted within the context of climate change impact assessments. Recently, many authors have highlighted that the focus of vulnerability conceptualisations needs to be on the endogenous social and political context within which vulnerability is set (Birkenholtz, 2012; IPCC, 2014; O'Brien et al., 2007; Sietz, 2011; Wisner et al., 2012). Within climate change literature, vulnerability is largely conceived of as an adverse outcome of various stressors, including climate variability and extremes. It is now established that incorporating these hazards and exposures within a vulnerability framework brings large uncertainties into assessments. While vulnerability is present, the future remains a large uncertainty; any attempt to incorporate future vulnerability or future impacts such as climate change and policy changes can at best be inadequate or inferred evidence (Reed & Stringer, 2015). Thus, in this study, vulnerability is conceived of as an endogenous concept, assumed as a pre-existing state of the system, in line with IPCC's AR5 (2014)[88].

Vulnerability is defined as, "the propensity or predisposition of a system to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014: 128). Thus, the two main elements of vulnerability are 'sensitivity' and 'adaptive capacity' (or the 'lack of adaptive capacity'), represented as follows:

$$V = \int (S, AC)$$

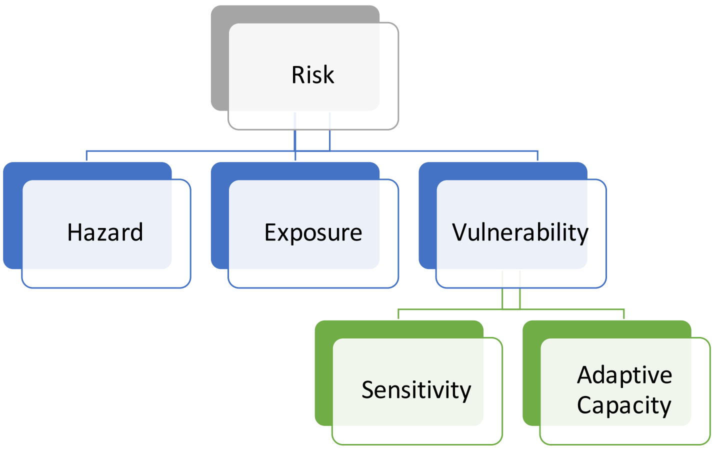
In this equation, V is endogenous vulnerability of the household, S is the sensitivity of a household to any stressors and AC is the adaptive capacity of a household to cope with any stressors.

Sensitivity is defined as the susceptibility of a system to a stress or perturbation (IPCC, 2014). In assessing sensitivity, the focus lies in understanding the human and/or environment conditions that can improve or worsen the impact of a stressor. For example, a drought will have a greater impact in reducing the crop yields of a farmer with severely degraded land (ecological sensitivity) when compared to a farmer with good quality land. **Adaptive capacity** refers to the ability of the system to evolve in a way that minimises the damage caused by the

[88] Hazard and exposure are thus not dealt with within the vulnerability framework in this chapter (Figure 2.4). Analysis in Chapter Five provides evidence that the people, livelihoods, species, and ecosystems in Jodhpur are highly exposed to the combined effects of climatic variability and dryland degradation.

stressor. For example, to reduce the impact of drought on crop yields, the farmer may use groundwater or harvested rainwater. This availability of water, minimises the damage caused on crop yields. However, harvesting either groundwater or rainwater requires access to technologies (modern and/or traditional), knowledge, and finances among other factors; access in turn is linked with a farmer's adaptive capacity. A farmer's inability to assimilate and use harvested rainwater or groundwater during drought demonstrates the **lack of adaptive capacity** (Sietz, 2011). Figure 6.1 illustrates the concepts.

Figure 6.1: Risk, hazard, vulnerability and exposure. Risk arises from an interaction of hazard, exposure and vulnerability. Vulnerability is the endogenous characteristic of a system and is determined by its sensitivity and (lack of) adaptive capacity



As indicated in Chapters Two and Four, the conceptualisation of vulnerability as endogenous to a system is yet to be extensively applied in vulnerability studies, especially within drylands (Reed & Stringer, 2016). As of 2017, most published studies, both globally and in India, use the outcome (or end-point) approach, presented in IPCC's third and fourth assessment reports (AR3 and AR4) incorporating concepts of exposure and hazards within the vulnerability framework (Jurgilevich et al., 2017; O'Brien et al., 2004b; Rao et al., 2016; Shukla et al., 2017). A systematic review of vulnerability assessments conducted in India by Singh et al. (2016) reiterates a number of the key critiques of global vulnerability research identified in Chapter Two. In addition, the authors highlight that the interactions and feedback effects of current climate variability with highly political and contested factors such as changing caste dynamics, rising inequality, or political will and fund allocation are rarely captured in vulnerability research in India (ibid.).

The literature review in Chapter Two identified two critical unresolved issues in vulnerability research in drylands:

(i) There is a gap in the knowledge of the suitability and/or applicability of different assessment methodologies; and in particular there is a lack of consensus on the relevance of composite vulnerability indicators for differing dryland agro-ecosystems; and

(ii) There is limited knowledge of how to incorporate the dynamic nature of vulnerability in drylands.

These knowledge gaps have arguably limited the usability of some of the rich contextual information often present in place-based studies of vulnerability. The usability of vulnerability frameworks is especially important in India. The development of vulnerability profiles at national, state, and district level has been made a priority since the Paris Agreement, which requires reporting on vulnerability assessments. India's MoEFCC has also set forth guidelines for all state and district authorities to prepare vulnerability profiles; the MoEFCC intends to use these vulnerability profiles in reporting to the UNFCCC, and in approving Adaptation Fund projects under the pilot National Adaptation Fund on Climate Change (NAFCC)[89] (MoEFCC, 2016).

The methodology adopted in the remainder of this chapter attempts to address these gaps and provide a useable framework of vulnerability.

6.1.2. Approach to assessment of endogenous vulnerability

As explained in Chapter Four (Section 4.3), two methods are used in this study for the assessment of endogenous vulnerability, so as to overcome the difficulties commonly encountered in vulnerability assessments. Both these methods incorporate community perspectives at multiple scales:

1. A quantitative index-based assessment of vulnerability – **'Agriculture and Livelihoods Vulnerability Index'** (AgLiVI) - is developed. It is tailored specifically for this study, through the use of criteria and indicators that represent either the sensitivity or lack of adaptive capacity of a particular household. Indicators are chosen that are relevant to the communities, using both objective and subjective measures[90]. This addresses common criticisms of vulnerability indicators having relevance only in the context of 'objective' scientific inquiries (Whitfield et al., 2011). In addition, novel indicators representing a cluster's social dynamics and maintenance of traditional capacities (e.g. rainwater harvesting) are incorporated within the index. Most vulnerability assessments, particularly in India, are conducted at a higher scale, e.g. district-level assessments (Brenkert & Malone, 2005; O'Brien et al., 2004b; Rao et al.,

[89] The National Adaptation Fund on Climate Change (NAFCC) was established in 2015-2016 to help in scaling up of climate change adaptation interventions in accordance with the national and state level action plans.

[90] Objective in this index refers to indicators that involve impartial or non-biased values. They are generally straightforward to denote a value to: i.e. number of members in the household; Subjective measures involve perceptions or opinions. They are more difficult to denote a value to: i.e. Do you perceive your cropland to be severely degraded, moderately degraded or not degraded? Each subjective answer is given a value on a scale e.g. 1 (not degraded) to 3 (severely degraded).

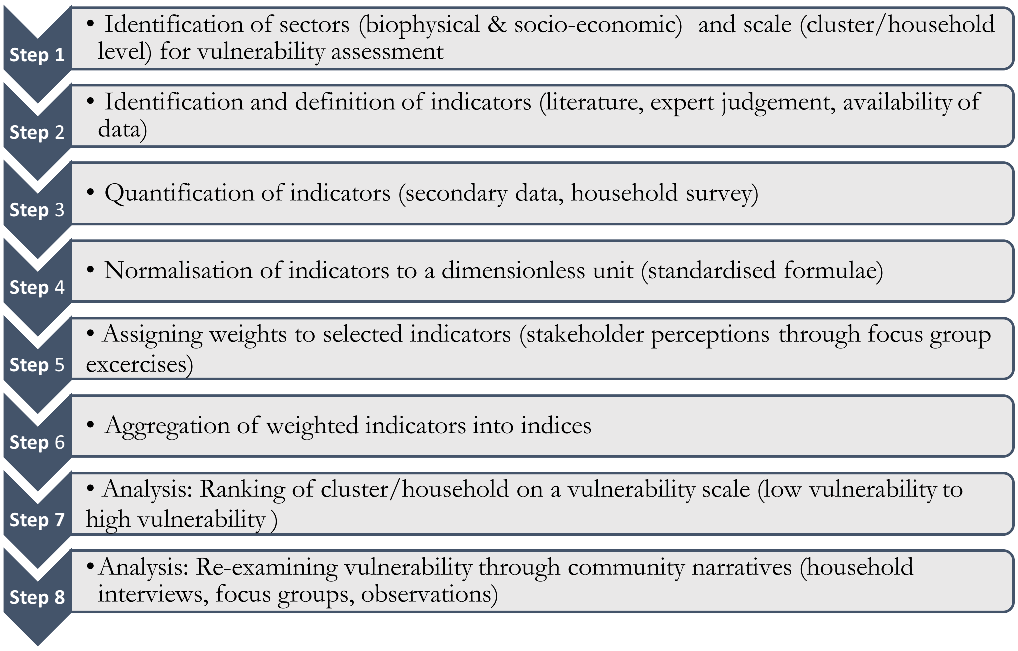
2016), and use indicators with readily available secondary sources of socio-economic and biophysical data[91]. In this assessment, socio-economic, biophysical, and institutional indicators are combined into the AgLiVI.

2. A qualitative narrative-driven approach is conducted, from the rich information gathered from the field to enhance the vulnerability assessment. The qualitative analysis investigates vulnerability through the following principles: (i) it uses community-based interpretations of socio-ecological sensitivity thresholds; (ii) it critically appraises the 'reliability of access' to resources and extension services, through the prism of local power and politics; (iii) it incorporates discussions on sustainability into appraisals of current adaptive capacities.

Through the above, the analysis will demonstrate that even when vulnerability is studied in the present time i.e. current vulnerability, consideration can be given to the dynamic and fragile nature of drylands.

An overview of the key stages involved in broader vulnerability assessments have been discussed in Chapter Four; Figure 6.2 summarises and presents these stages. In Section 6.2 and 6.3, the results from the AgLiVI (steps 1-7 in Figure 6.2) are presented. Following this, Section 6.4 presents analysis from the qualitative vulnerability assessment (step 8 in Figure 6.2). The aim of the analysis is to present a grounded, empirical framework of socio-ecological vulnerability for dryland agro-ecosystems.

Figure 6.2: Framework and approach for vulnerability assessment



Source: Adapted from Esteves et al., (2016)

[91] Appendix II provides a summary of indicators used in important vulnerability assessments conducted in India.

6.2 Results of the Agriculture and Livelihoods Vulnerability Index

This section presents the results of the AgLiVI assessment and describes the:

(i) Selection of criteria and indicators and methods of quantification for each (Table 6.1);

(ii) Assignation of weights for the selected criteria and indicators through local stakeholder participation (Table 6.2); and

(iii) Development of a final vulnerability index, aggregated for households, villages, and clusters (section 6.2.5).

Details of the methods followed in selecting, combining, and aggregating criteria and indicators are provided in Section 4.3. The stages of the vulnerability analysis are discussed below and coincide with steps 1-7 in Figure 6.2.

6.2.1 Selection of sectors and scale

The vulnerability assessment in this study covers 'agriculture' and 'livelihoods'. During the pilot study, discussions with communities and local scientists prompted an analysis of agriculture criteria independently of livelihoods criteria. 'Agriculture' refers to cropland, cropping practices and cropping-related indicators. 'Livelihoods' refers to other important elements of a particular household, such as livestock, agro-forestry, social systems, and institutions. Finally, vulnerability is calculated and presented together for the two clusters, as an 'agriculture and livelihoods vulnerability index' (AgLiVI).

The use of two distinctive clusters and multiple scales within these clusters is expected to enrich findings, ensuring generic and macro-scale results on vulnerability are not produced for the diverse social groups and situations represented in this study area. Rationale for the selection of clusters is discussed in Chapter Four. The three scales of assessment are:

(i) Cluster level: Cluster I is predominantly rain-fed and Cluster II is predominantly irrigated.

(ii) Village-level: 10 villages are chosen, five villages within each cluster

(iii) Household level: 163 households interviewed, 79 households in Cluster I and 84 households in Cluster II.

6.2.2 Selection of criteria and indicators

In this study, a total of eight criteria and 31 indicators were selected for the analysis. Drawing on vulnerability assessments from India in general and Rajasthan in particular (Esteves et al., 2016; Gerlitz et al., 2016; Rajesh et al., 2014; Rao et al., 2016; Singh & Nair, 2014), criteria were first identified, followed by a list of indicators for each criterion (see Table 6.1). Both criteria and indicators were then re-evaluated and a final list developed using local knowledge from the communities in question. The methodology integrates established objective (easily quantifiable) indicators that are traditionally used in vulnerability assessments in India alongside atypical subjective (perceptions-based) indicators. Examples of objective indicators include, the number of income sources, number of livestock owned, and percentage area irrigated, among others. Subjective indicators quantify perceptions of the communities on a few key indicators such as: (i) state of land and groundwater resources, ranked by respondents on a scale of 1 (no degradation) to 3 (high degradation); and (ii) agricultural productivity, estimated using respondents' perceptions of the average reduction in crop yields over five years.

Throughout, the quality and value of selected indicators were critically scrutinised. In traditional vulnerability assessments, access to drinking water, institutional support including government programmes[92], and formal loans are typically measured through 'presence' rather than 'access' (see Rao et al., 2016; Shukla et al., 2017). Here it was only given a value in the index, if a respondent reported moderately frequent access or use. While a seemingly obvious inclusion, a majority of the assessments conducted in India neglect this critical difference between 'presence' of an institution/service/resource and 'access' or utilisation of the same. For instance, access to drinking water is often measured through presence of a well or a water pipe in the village (Brenkert & Malone, 2005; Rajesh et al., 2014). In this study, access to drinking water was only given a value in the index, if respondents conveyed moderate access (which in the villages selected is at least twice a month). Table 6.1 provides a final list of selected criteria and indicators. The selected indicators conform to the definition of vulnerability highlighted in Section 6.1.1 and represent the sensitivity and/or lack of adaptive capacity of the selected households. Indicators were developed separately for agriculture and livelihoods and finally aggregated as the Agricultural and Livelihood Vulnerability Index (AgLiVI). A description of selected criteria is provided.

For agricultural vulnerability, four primary criteria were chosen, and within each criterion a number of indicators. Rationale for the selection and enumeration of these indicators is shown in Table 6.1 and criteria are briefly discussed below.

1. State of land and water resources: Land is typically in a fragile yet resilient state in dryland agro-ecosystems (Safriel, 2009). The drylands of western Rajasthan have maintained diverse flora and fauna in addition to supporting growing human and livestock populations despite long and frequent spells of drought (Kar et al., 2009). The ability of land to remain resilient is however on the decline through greater pressures from anthropogenic and climatic factors. Groundwater resources are included for assessment as dryland farmers in the district are increasingly dependent on groundwater-led irrigation.

[92] Such as the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGA) provides 100 days of wage employment in a year within the village for those households in need of support/ help. It is discussed in further detail in Section 6.5

Groundwater is also severely threatened as shown in Chapter Five. Overall, the sensitivity of the natural resource base is high which in turn heightens the sensitivity of communities that live off this land. Degraded land has reduced soil depth, organic matter, and fertility and is less able to tolerate shocks. The use of poor quality groundwater leads to salinity, exacerbating dryland degradation (Chapter Five). This has wider implications in terms of lowering crop productivity and increasing food insecurity.

2. Crop productivity: Respondents understood that land degradation and land productivity are not interchangeable concepts (Chapter Five). They indicated that while land can be productive in the near-term, it can still remain of poor quality in the medium and long-term. Productivity is also closely related to land holding size, as larger landholders have the ability to grow more crops, and intensify cropping through the use of fertilizers and irrigation.
3. Diversification of cropping patterns: Risk-averse farmers in the region rely on a number of diversification strategies including:
    - Growing a wide variety of crops (three or more);
    - Mixed cropping, where seeds of different *kharif* crops are mixed together before sowing. If one crop fails due to moisture stress or pests, other crops help retain income stability;
    - Change in time of sowing, where farmers can speed-up or delay key activities such as sowing, harvesting, based on rainfall patterns.

    Information on farmers' ability to remain flexible with sowing times in response to rainfall patterns was collated but the data was difficult to enumerate for the index. It is used in the discussion in later sections.
4. Access to agricultural inputs: Agricultural productivity received a major boost through the development of inputs such as HYV seeds, fertilizers to improve soil fertility of depleting lands and tractors for quicker land preparation. For instance, information from global studies on the impacts of Green Revolution-inspired agricultural growth show that the average yields of staple crops such as rice, wheat, and maize have more than doubled, especially in areas with access to irrigation (Denning et al., 2009; Patil et al., 2015; Turner, Matson, et al., 2003).

In the context of livelihood vulnerability, the following four primary criteria were chosen, and measured using indicators (provided in Table 6.2).

1. Diversification of livelihoods: The number of income/livelihood sources increase manifold a household's ability to diversify its risk portfolio (IPCC, 2014; Ruano & Milan, 2014). These could be in the form of economic wealth accumulation or through the

inclusion of additional ways of gathering food and fuel. If one source of livelihood fails, e.g. crop failure, other sources (e.g. livestock) can provide suitable alternatives.

2. Social dynamics: In the rural areas of Jodhpur, understanding of culture (including ethnicity, religion, social networks) is paramount because resource-access and resource-use are closely tied in with the social dynamics of their livelihoods. While the complexity of societal networks and inter-intra household dynamics are difficult to capture using quantitative methods, an attempt to incorporate these was made through the use of the five indicators given in Table 6.1. A household's social location (with respect to the main village power dynamics) can have a significant impact on both sensitivity and ability to access resources and support (Bankoff et al., 2015).
3. Access to livelihood support systems and institutions: Differential access to material, social, natural, and political resources is one of the main driving forces behind determining vulnerability. Wisner et al. (2003) show that through access to better services, including information (through radio), transport (private vehicle) and insurance (for livestock), wealthy farmers are better prepared during a cyclone. In addition, the government is implementing several programs to help rural communities cope with any stresses (e.g. MGNREGA).
4. Maintenance of traditional capacities: Communities have strong indigenous knowledge of how their land and related resources respond to different situations (Kattumuri et al., 2017). Their innate understanding gained through centuries of living in the region have led to strong capacities that help them deal with varying external events (Prasad et al., 2004; Varadan & Kumar, 2014; Wahyudi et al., 2012). The stronger their ability to tap into their natural coping mechanisms, the better they are able to survive. A farmer who harvests rainwater will be better prepared when piped water is stopped for three months (as was reported to often be the case in the study villages). Although rarely incorporated in vulnerability assessments, they represent an important characteristic of dryland community resilience and are thus included in this study. A number of traditional capacities are present in the two study clusters (as discussed in Chapter Three). For the AgLiVI, two indicators in particular were chosen for assessment: (i) the reliance on rainwater harvesting was chosen since water is the major limiting factor in the area and; (ii) the use of traditional storage huts (*kothas*) for grains and fodder in preparation for bad/drought years were chosen since food security is another key limiting factor. Traditional capacities to adapt are rarely included in most vulnerability estimations.

6.2.3 Quantification and normalisation of indicators

Once indicators were chosen and organised, the next step was to quantify them, so as to compute the index values for each cluster. In Section 4.3, the methodology followed in the quantification and normalisation of criteria and indicators is described. In this study, functional relationships were used to normalise the criteria and indicators[93]. Table 6.2 provides details on the indicators, their functional relationship with vulnerability and the rationale for using a positive (+) or negative (-) functional relationship. The functional relationship[94] was mainly determined using similar studies on vulnerability in India, such as the ICAR study by the Govt. of India (Rao et al., 2016). This information was also corroborated with respondents. For instance, migration was initially given a negative functional relationship with vulnerability i.e. the more people migrating, the lower the households' vulnerability (migrating members help earn additional sources of income, and put less pressure on their land). After speaking with the respondents, it was re-calibrated as a positive functional relationship. This was because respondents reported that migrating fro for 8-9 months a year was increasing their vulnerability. Men who migrate reported that it de-stabilised their households for more than half the year; taking them away from the one occupation they are skilled at - agriculture in this case. Women also reported that men who were away for a majority of the year rarely sent remittances to support their village-based activities.

[93] Chapter Four, Section 4.4 provides details of the functional relationships followed in the assessment

[94] The vulnerability index is a static measure, used to understand current vulnerability (Hahn et al., 2011). Therefore, functional relationships relate to current use values of indicators. For instance, irrigation may not be a sustainable long-term strategy (due to loss of groundwater reserves). However, in the present time, farmers without irrigation have a lowered capacity to adapt in comparison with farmers with irrigation (who are able to crop in multiple seasons, being less dependent on rainfall). The longer-term implications are examined in more detail in the qualitative analysis presented in section 6.4.

Table 6.1: Vulnerability criteria and indicators, methods of measurement, functional relationship and rationale

	Vulnerability criteria	Vulnerability indicators	How is it measured?	Functional relationship with vulnerability	Rationale
Agriculture	**State of key resources**	State of land degradation	Ranked by respondents on scale: 3: Severely degraded 2: Moderately degraded 1: No apparent degradation	+	Due to the heavy dependence on land resources degradation can have large scale implications on livelihoods, leading to heightened sensitivities.
		State of groundwater		+	Groundwater-led irrigation, has become a critical support system for dryland farmers in the region. While it helps reduce reliance on uncertain rainfall patterns, increased degradation of GW resources will increase sensitivity.
	Productivity	Reduction in crop yields	average reduction in crop yields over the past 3-5 years, expressed as a percentage	+	Crop yields are a key indication of the health of their agricultural system. Declining cropping patterns, signify a loss of income and food security
		Size of land holding	No. of hectares of land owned	-	Larger farms have benefits such as greater scope for crop diversification, increased crop yields and reduced agricultural intensification.
	Diversification of cropping patterns	Types of crops grown	No. of crops grown	-	Crop diversification helps farmers spread the risk across different crops, increases yields and provides security from pests, frost, wild animals etc.
		Mixed or mono cropping	Use mixed-cropping techniques? 1: Yes 0: No	-	Mixed cropping offers many benefits such as efficient utilisation of land, water, labour and inputs; prevents pests; diversifies risk during adverse climate; and promotes soil fertility.
	Access to agricultural inputs	Dependence on irrigation	Proportion of area without irrigation	+	Irrigation increases farmers' ability to adapt by decreasing their dependence on rainfall. It also provides opportunities to diversify cropping to include cash crops that require additional water. The greater the area without irrigation, the greater the current increased vulnerability.
		Use of hybrid seeds (HYV)	Use hybrid seeds? 1: Yes 0: No	-	HYV seeds develop faster than local varieties, which is beneficial in climates where timing and intensity of rainfall is unpredictable.

		Amount of fertilizers used	Kg/ha (of urea and DAP)	-	The use of fertilizers in nitrogen and phosphorous-poor soils improves crop productivity in th e present and enriches capabilities in irrigated soils. Increases in productivity will reduce vulnerability.
		Intensity of machinery	No. of times tractor used in last cropping season	-	Tractor use reduces the drudgery of agriculture, and provides greater depth of tillage, which in turn promotes soil fertility and reduces vulnerability.
Livelihoods	**Diversification of livelihoods**	Diversity of income sources	No. of income sources	-	Households (HH) whose livelihoods are derived from multiple resource types or sectors are likely to have lower vulnerability. It helps to diversify risk, manage seasonality and remain flexible; this leads to better adaptive capacity.
		Dependence on agriculture (crop and livestock)	Primary and secondary source of livelihood from cropping and livestock.	+	HHs whose main source of income depends on land resources and climate are less able to diversify their livelihoods; this makes them more susceptible to stresses on resources, increasing vulnerability
		Livestock owned (type)	How many different types of livestock do they own?	-	Livestock provide an alternate source of income (through the sale of livestock), milk for consumption and provide invaluable manure for cropland.
		Livestock owned (no.)	No. of livestock (total)	-	
		Agro-forestry species (types)	How many different species of trees on their farmland and homestead?	-	Presence of greater varieties and number of agro-forestry trees provides HHs with fodder, fuelwood, food and medicinal value, and increases their capacity to adapt.
		Agro-forestry species (no.)	No. of trees	-	
		Migration	% members migrating/HH	+	Seasonal migration of male members for employment, reduces the coping capacities of household members left behind. Migrated members also lose their sense of identity which until recently was closely tied to their land.
	Social dynamics	Size of family	No. of HH members	-	Larger families help diversify risk as different family members are employed in different sources of livelihood. More members also help provide emotional support during adversity, reducing a household's sensitivity.
		Gender	No. of women/HH	+	Women, due to their position in Rajasthan's patriarchal society, generally do not approach institutional support systems, like crop compensation, this increases their immediate sensitivity.
		Education level	% HH members attended	-	Education enhances an individual's capacity to understand and

			secondary school		utilise information. It also increases the individual's and their HH's feeling of self-worth within their community, reducing sensitivity.
		Skill level	% HH members skilled/semi-skilled (other than agriculture) e.g. teacher, mechanic, blacksmith.	-	Skilled workers have the capacity to work in non-climate dependent sectors, they are able to seek alternative sources of income security, reducing sensitivity.
		Caste	1: Lower caste 2: Middle caste 3: Higher caste	-	HHs belonging to the upper echelons of the caste system are likely to have lowered sensitivity, due to their ability to maintain social standing within and outside the community.
	Access to livelihood support systems	Markets	Pukka road nearby? 1: Yes; 0: No	-	A paved road provides increased opportunities for public and private transportation, which in turn are essential to connect remote rural communities to markets in local towns and cities.
		Fuel	Availability of LPG: 1: Yes; 0: No	-	HHs with access to LPG require less fuelwood from trees. LPG provides significant health benefits to rural women, they do not suffer from respiratory disorders that are caused by fuelwood-based cooking and heating.
		Sanitation	Toilet in the HH or nearby (500m) 1: Yes; 0: No	-	Improved access to sanitation is an essential step towards promoting safe and sanitary practices essential to a healthy life.
		Domestic water	Moderate quality water and frequent connectivity? (twice a month) 1: Yes; 0: No	-	Connection to moderate quality drinking water is essential for the survival of both humans and livestock in this water-scare region. Access to water significantly improves capacity to adapt.
		Formal loans	Do they have any current formal loans from bank or co-op society? 1: Yes; 0: No	-	Access to legal financial institutions provides communities with financial aid in times of need and improves their overall capacity to adapt.
		Informal loans	Do they have any loans taken out from local moneylenders? 1: Yes; 0: No	-	Informal loans are indicative of HHs who have strong networks within the community, this allows access to loans and help, especially for those that are unable to access formal loans. This increases their capacity to adapt as during distress or disasters informal loans allow for immediate access to credit during distress or disasters (although at times subject to high interest rates).

		MGNREGA (national rural employment guarantee scheme for rural India)	Job cards and regularity of work (completed at least part of the 100 days of wage employment) 1: Yes; 0: No	-	Regular access to government support programmes such as MGNREGA provides households, especially women, with additional livelihood security.
	Traditional capacities	Rainwater harvesting	Do they use rainwater harvesting for partly fulfilling water needs? 1: Yes; 0: No	-	Indicative that HHs are well-adapted to the variable conditions of water availability in the region and resilient to any sudden changes in water supply.
		Storage of grains	Do they use traditional grain storage? 1: Yes; 0: No	-	Storage of grains for bad years, improves resilience by managing food and grain fodder shortage sustainably.

6.2.4 Development of weights for criteria and indicators

Assigning weights is an important step in aggregating indicators (Gerlitz et al., 2016). In this study, weights were obtained from the primary stakeholders i.e. the communities. Weights (equating to 100%) were only taken for the primary criteria of significance given in Table 6.2. Following this, in conducting the analysis, equal weights were assigned to the set of indicators under each criterion. For example, in the table below, the state of key resources was given a weight of 18% (0.18) by the stakeholders[95]. The two indicators under this criterion (state of land, state of groundwater) were each given a value of 0.09. More details on the selection and estimation of weights are given in Chapter Four (Section 4.3).

Table 6.2: Weighting given to primary vulnerability criteria

IPCC categories	Vulnerability criteria of significance	Priority weights (totally a 100*)
Sensitivity	State of key resources	18 (0.18)
	Productivity	12 (0.12)
	Social dynamics	16 (0.16)
Adaptive capacity	Crop diversification	10 (010)
	Access to agricultural inputs	15 (0.15)
	Livelihood diversification	15 (0.15)
	Access to livelihood support systems	10 (0.10)
	Maintenance of traditional capacities	4 (0.04)
Total		**100 (1)**

**Figures in parenthesis are for a total 1 on a scale of 0-1*

At this stage, for ease of discussion, the primary criteria are further restructured into the two IPCC categories of sensitivity and adaptive capacity. The criteria that best demonstrate the human or environmental conditions that determine the degree of sensitivity are classified under sensitivity; while criteria that demonstrate the capacities of a household to adjust to a hazard are classified under adaptive capacity.

Among the eight vulnerability criteria selected for this study, the 'state of key resources' was given the highest weight (0.18) followed by social dynamics (0.16), while the maintenance of traditional capacities (0.04) was given the lowest weight. It is noteworthy that communities perceive what is likely their most resilient attribute, as the least important[96]. This is not surprising; perceptions of what holds value in these communities have changed significantly as a result of continuous interventions brought on by market-led transformations in and around

[95] The stakeholders placed 18 sticks out of a 100 placed under this criterion.
[96] Authors such as Nyong et al., (2007) highlight the value of indigenous knowledge in improving adaptive capacities.

their region. These transformations have presented communities with notions of wealth and prosperity that do not align with their more traditional ideals of successful livelihoods.

Overall, the vulnerability index for drylands, called the AgLiVI, was developed by multiplying the normalised and weighted values for each indicator, followed by an aggregation of all 31 indicators for each household. The AgLiVI captures the extent to which a household is susceptible to harm (sensitivity) and its lack of ability to adapt to these changes (lack of adaptive capacity)[97].

The index scores for each sub-component vary from 0 to 1, where 0 represents minimum vulnerability and 1 represents maximum vulnerability. The aggregated AgLiVI score represents the combined sensitivity and lack of adaptive capacity for each household. The scores of all households are aggregated for each village, and finally for the two clusters.

6.2.5 Identification of vulnerable communities: Who is vulnerable?

Results from the AgLiVI show an overall index value of 0.56 for Cluster I and 0.63 for Cluster II. Both clusters have high vulnerability scores on a scale of 0 to 1. Within each cluster, there are many differences between villages and households.

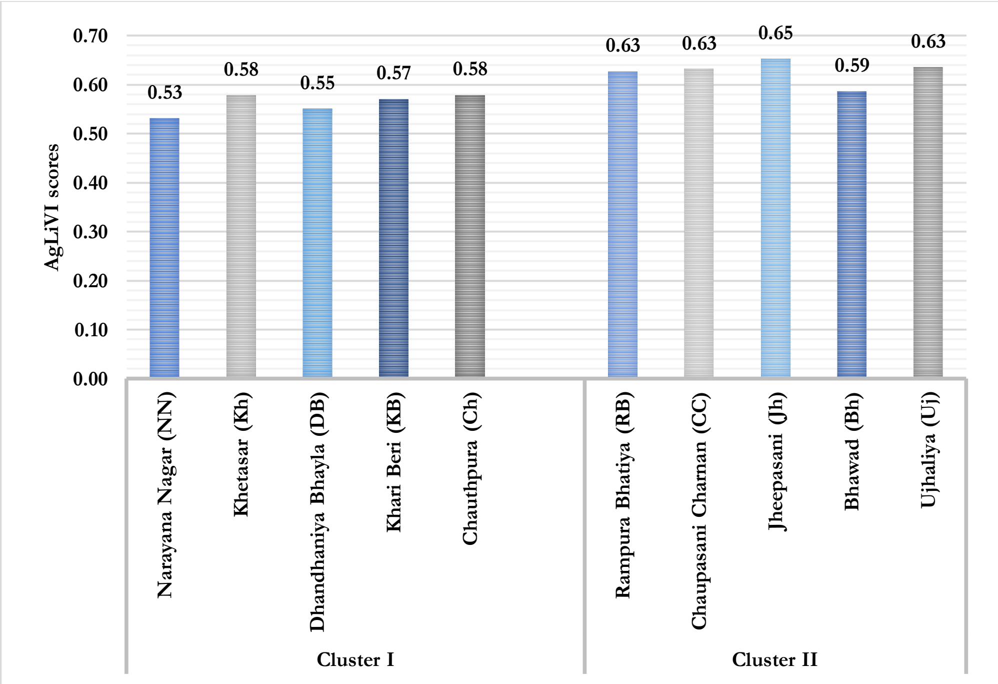
The AgLiVI scores of the ten villages selected for the study are presented in Figure 6.3 below. The figure shows that all villages are vulnerable (on a scale of 0-1). It illustrates clearly the clustering of villages, with Cluster I villages representing relatively lower vulnerability scores, in comparison to the villages in Cluster II. All villages show high vulnerability scores. Cluster I villages have a range of index values from 0.53 to 0.58; and Cluster II villages have a range of index values between 0.59 and 0.65. Within Cluster I, the villages of Chautpura (Ch) and Khetasar (Kh) (0.58) are the most vulnerable, with the highest AgLiVI scores, followed closely by Khari Beri (KB) (0.57), Dhadhaniya Bhayla (DB) (0.55) and Narayana Nagar (NN) (0.53). In Cluster II, Jheepasani (Jh) is the most vulnerable with the highest AgLiVI score (0.65), followed by Ujaliya (Uj), Chaupasanai Charnan (CC) and Rampura Bhatiya (RB) (0.63); while Bhawad (Bh) has the lowest AgLiVI score (0.59) in Cluster II.

For ease of discussion, the vulnerability of individual households is often ranked on different scales (e.g. 1-5 or 1-10). The 1-5 scale is common in vulnerability assessments and standardises the scoring system such that households can be compared with each other (Balica et al., 2012; Rao et al., 2016). It is to be noted that as is common within vulnerability index estimations,

[97] In practical terms, while calculating values of the index, lack of adaptive capacity was estimated in the index (as opposed to 'adaptive capacity'). Lack of adaptive capacity is a better reflection of concepts of vulnerability used in this thesis and evaluated in the index. For instance, vulnerability is defined by the IPCC (2014) as including 'sensitivity' or susceptibility to harm and 'lack of capacity to cope and adapt'. To provide an example of a criteria from Table 6.2 above, lack of crop diversification has a negative relationship with vulnerability, where the fewer the number of crops grown, the higher the vulnerability (see Rajesh et al., 2014; Gerlitz., et al 2016)

ranking is not an absolute measure; rather it is a relative measure between selected households. The ranking of households within a vulnerability index is the main practical output typically extracted from vulnerability assessments by policy and development planning.

Figure 6.3: Vulnerability scores by village in Cluster I and II



Vulnerability ranking is used mainly to target vulnerability-reduction programmes towards the most vulnerable. For instance, CRIDA's Agricultural Vulnerability Atlas prepared for the Government of India, highlights the following: "districts ranked 'very high' and 'high' vulnerability, are in the states of Rajasthan, Gujarat, Uttar Pradesh and Madhya Pradesh. Investments that enhance adaptive capacity and resilience may be targeted in these districts, along with targeting and prioritising investments for technology development and innovation" (Rao et al., 2016). A ranking of the vulnerability of units of scale (households, villages, clusters) is therefore likely to be the most important practical output appropriated from a vulnerability analysis.

In this study, a scale of 1 to 5 is used and the ranking is done simply by multiplying the index value of each household with 5 (very high vulnerability), arriving at a vulnerability rank of 1 to 5, where a rank of 1 signifies a household has very low vulnerability and a rank of 5 signifies a household is highly vulnerable (Esteves et al., 2016). Vulnerability rankings at the household level for each cluster are presented in Table 6.3. A majority of households in both clusters have a rank of 3, showing moderate-high vulnerability.

Table 6.3: Percentage households within each vulnerability ranking

Vulnerability Rank (1=Very low; 5=Very high)	Cluster I (% households)	Cluster II (% households)
	AgLiVI	AgLiVI
1	0	0
2	14	1
3	79	87
4	2	11
5	0	0

Despite its significance in policy planning, ranking has garnered little use in scientific research. Vulnerability index values and the ranking of indicators are seen as ambiguous quantifications of vulnerability. As Sharma (2015) states, the quantification remains largely conceptual in its utility since the value does not have any stand-alone significance, and is mostly drawn in to compare the vulnerability of one household with another. Furthermore, the ranking of households does not capture the movement of households in and out of vulnerability groups (Carter & Barrett, 2006)[98]. The practical significance of the vulnerability index therefore lies in the interpretation of the key criteria and indicators driving the vulnerability of households and clusters. The next section provides details on the drivers of vulnerability.

6.2.6 Drivers of vulnerability: Why are they vulnerable?

As shown in Table 6.1, eight overall criteria (each a composite of several indicators) are selected in both the study clusters to construct a comparable AgLiVI for each cluster. The contribution of major criteria to overall household vulnerability in each cluster is presented in Figure 6.4. Results show that the poor state of land and groundwater resources, declining agricultural productivity, lack of livelihood diversification, and prevailing social dynamics are the key drivers of vulnerability. The significance of the contribution of each criterion to endogenous vulnerability is presented as a radar plot, and the dimensions of vulnerability are represented by spokes of the plot – the greater the significance, the further away from the centre of the plot.

[98] A methodology for improving the ranking of vulnerability is developed in Chapter Seven.

Figure 6.4: Drivers of AgLi vulnerability for Cluster I and Cluster II

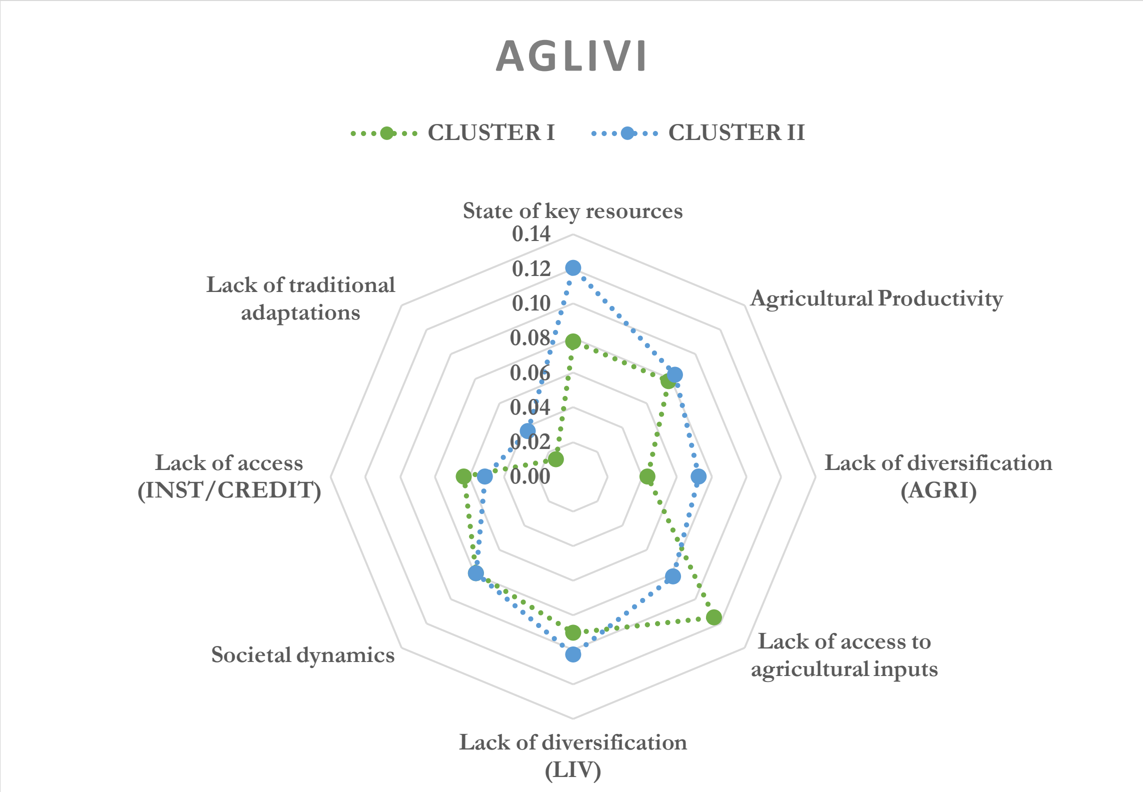
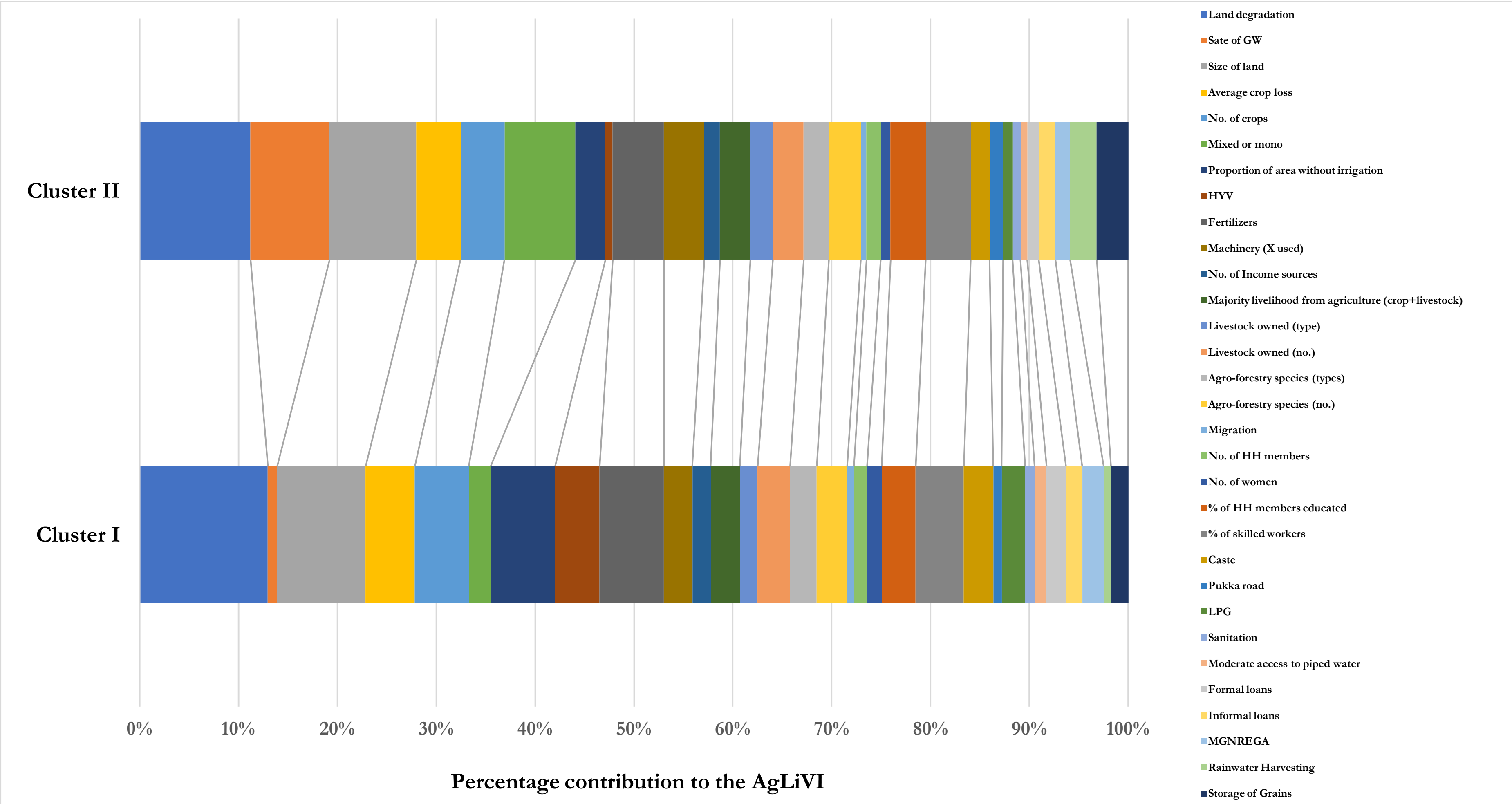


Figure 6.4 shows that the factors driving vulnerability of Cluster I include lack of access to agricultural inputs (22%), lack of livelihood diversification (14%), societal dynamics (14%), land and groundwater degradation (14%), and poor agricultural productivity (14%). In Cluster II, vulnerability is driven by land and groundwater degradation (20%), lack of livelihood diversification (16%), poor agricultural productivity (13%) and societal dynamics (13%). The calculated AgLiVI values are given in Appendix VI.

Figure 6.5 shows the breakdown of the AgLiVI index value of the two clusters in the form of the relative contributions of all 31 vulnerability indicators[99]. In both clusters, land degradation is the most significant driver of vulnerability. In Cluster I, lack of area under irrigation is also a critical driver of current vulnerability (only 2% of households reported use of irrigation). Overall, in both clusters, the indicators of agricultural vulnerability contribute to more than 50% of the index when compared with indicators of livelihood vulnerability. This demonstrates the importance of differentiating agricultural vulnerability from livelihood vulnerability within assessments.

[99] Appendix VI provides the values of the contribution of each of the 31 vulnerability indicators shown in Figure 6.5

Figure 6.5: Relative contribution of all selected vulnerability indicators by cluster (in %)



In Cluster I, nearly all farmers (98%) practice only rain-fed *kharif* (monsoon) cropping. Rain-fed farmers have relatively lowered access to subsidised irrigation technologies and related inputs such as fertilizer subsidies[100]. Their lack of access to irrigation technologies and inputs is a key driver of their existing vulnerability (decreasing their capacity to adapt). On the other hand, their reliance on traditional cropping patterns such as the use of mixed cropping and traditional water management practices like rainwater harvesting has improved their capacity to adapt, as reflected in their lower agricultural vulnerability score. Similarly, despite only cropping in one season (*kharif*), food and livelihood security in Cluster I remains reasonably secure for the remainder of the year. This is largely due to better livelihood diversification through the presence of greater number and diversity of livestock and agro-forestry species, and a higher proportion of households with *kothas* for grain and fodder storage. As a result, although food availability is likely higher in Cluster II, due to double (*rabi*) and triple (*zaid*) season cropping, the lack of livelihood diversification and the lack of traditional storage capacities are driving vulnerability upwards.

6.2.7 Contribution of sensitivity and lack of adaptive capacity

Table 6.4 presents the contribution of the indicators of sensitivity and the lack of adaptive capacity to the AgLiVI score. Sensitivity in Cluster I is largely driven by a combination of land degradation, poor land productivity, and social dynamics. In Cluster II, degraded land and groundwater resources contribute to increasing sensitivity. As illustrated in Figure 6.1, in systems characterised by medium/high sensitivity, drawing on available buffers can easily absorb some or all negative impacts of negative shocks (Geest & Dietz, 2004). This buffer which prevents a sensitive household from potentially getting negatively impacted is its adaptive capacity. The lack of this preventive buffer or capacity can further increase vulnerability. Cluster I is most affected by poor access to agricultural inputs (in particular irrigation), which is offset to some extent by the presence of traditional capacities such as rainwater harvesting. In Cluster II, despite access to irrigation, respondents' adaptive capacity is lowered by their lack of both crop and livelihood diversification (relying primarily on cropping for income), with minimal reliance on traditional livelihood capacities.

In both the clusters, the lack of adaptive capacity is a larger contributor to vulnerability than sensitivity. In Cluster I, the lack of adaptive capacity contributes 58% to the vulnerability index, while in Cluster II it contributes 53% (see Figure 6.6).

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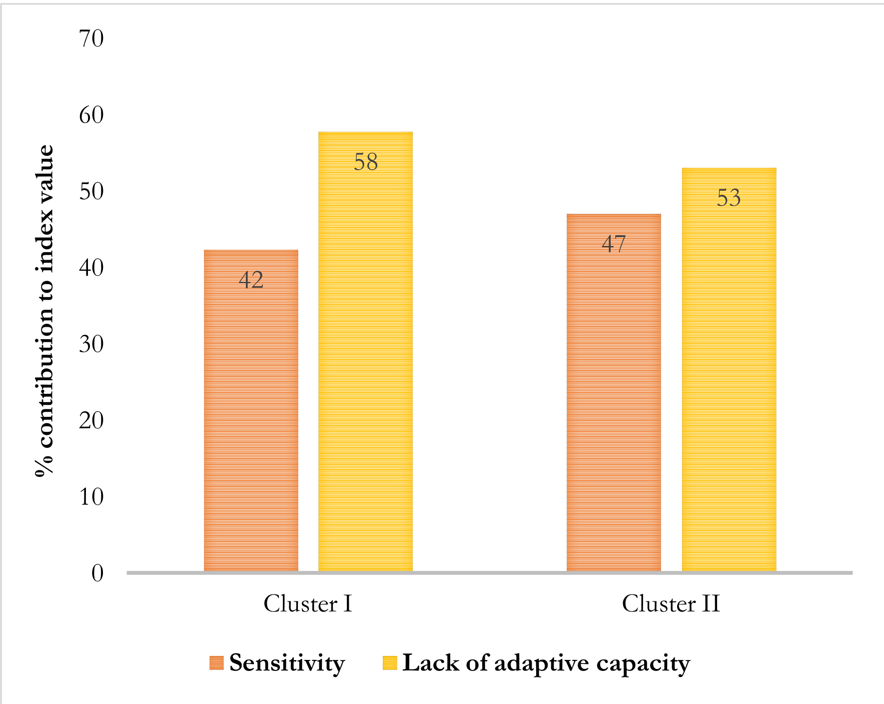
[100] Since cropping is done in only one season, although fertilizers subsidies are available, rain-fed farmers are less likely to go out of their way to avail of the subsidies due to the cost-effectiveness of investing in fertilizers for just one season.

Table 6.4: Relative contributing factors of the AgLiVI for Cluster I and Cluster II

IPCC categories	Vulnerability criteria of significance	Cluster I	Cluster II
Sensitivity (S)	State of key resources	0.08	0.12
	Crop productivity (declining)	0.08	0.08
	Social dynamics	0.08	0.08
Lack of adaptive capacity (LAC)	Lack of diversification of cropping patterns	0.04	0.07
	Lack of access to agricultural inputs	0.12	0.08
	Lack of diversification of livelihoods	0.08	0.09
	Lack of access to livelihood support systems	0.06	0.05
	Lack of traditional adaptations/coping capacities	0.01	0.04
Total Sensitivity (S)		**0.24**	**0.28**
Total Lack of Adaptive Capacity (LAC)		**0.32**	**0.34**
Total AgLiVI score (AgLiVI = S+LAC)		**0.56**	**0.63**

Index values should be interpreted as relative values to be compared within the study sample only. The AgLiVI is on a scale from 0 (least vulnerable) to 1 (most vulnerable).

Figure 6.6: Contribution of sensitivity and lack of adaptive capacity to the AgLiVI for Cluster I and II



6.3 Deciphering the utility of the vulnerability index

The results from the AgLiVI show that the prevailing endogenous vulnerability in both clusters is relatively high. Any external perturbations, whether it is climate variability, climate change, changes in market conditions, or policy changes, have the potential to further exacerbate already vulnerable conditions. The results show that Cluster II has a relatively higher vulnerability score than Cluster I. The findings are surprising in that, in reviewing vulnerability research conducted in India, communities with greater market access and irrigation capabilities are generally appraised to be the least vulnerable (Banerjee, 2014; Esteves et al., 2016; O'Brien et al., 2004b; Rao et al., 2016; Soora et al., 2013). This is because access to irrigation and markets makes farmers less dependent on variable rainfall patterns; they are able to ensure crop productivity and potentially practice winter (*rabi*) and summer seasons (*zaid*) cropping and; they are perceived to have greater food security. Therefore, the AgLiVI provides evidence that shows, vulnerability in arid zone agro-ecosystems to be atypical and unique in comparison with other sub-humid or semi-arid zones of India. In the arid drylands, irrigation and access to markets while providing benefits to both agriculture and livelihoods, are not in themselves adequate to mitigate the vulnerability to stressors, even in the present time. Discussions in Chapter Seven will explore these issues in more detail.

The analysis has thus far explored the analytical utility of using indicators to assess vulnerability in two dryland clusters of Jodhpur district. The vulnerability index, developed here as the AgLiVI, is adapted from methodology used in other vulnerability assessments; it is tailored to the region of study. The methodology employed a framework that enabled a selection of vulnerability criteria and indicators systematically, the application of community-derived weights, and the synthesis of a composite vulnerability index. In doing so the analysis makes four methodological contributions to the development of vulnerability indices for dryland agro-ecosystems:

(i) A fuller spectrum of indicators is incorporated:
- Local-level indicators derived from the communities themselves: such as social dynamics including caste hierarchy; maintenance of traditional capacities to adapt (e.g. reliance on rainwater harvesting and storage of food grains) among others;
- Middle-tier indicators typically used by development practitioners and policymakers: such as number of women per household, education and skill levels, among others;
- Whole system indicators used in broader national-level analysis: such as crop diversification, and percentage area under irrigation.

(ii) Provision of contrasting agriculture and livelihoods vulnerability across the different scales of households, villages and clusters of villages selected for the study;

(iii) Use of both objective and subjective valuations; and

(iv) Involvement of primary stakeholders in devising and assessing vulnerability criteria.

The strength of this approach is that it allows for a quick analysis and an easy comparison between households/villages/clusters. The selection of indicators is a largely transparent process and gives a clear picture of what indicators are impacting on what values. The transparency encourages periodic assessments, where indicators or weights can be changed keeping in mind the dynamic nature of vulnerability. It also enables the identification of the drivers of vulnerability across the two clusters, and assists in the targeting of vulnerability reduction or resilience building within those sectors or communities that need it the most.

Despite continued application, the use of indicators to assess vulnerability has been subject to intense scientific debate over the years (Adger, 2006; Hinkel, 2011; Lung et al., 2012; Tonmoy et al., 2014). There are a number of benefits of using a systematic index-based approach, as developed in this chapter and evidenced by the results. However, this approach can conceal a number of ambiguities and disadvantages. The nature of constructing an index demands quantification of certain attributes of a system. Despite incorporation of community perspectives within the construct of the index, a number of the socio-ecological interactions and cross-cutting issues are not easy to represent quantitatively or quantify accurately. The key drivers of vulnerability, derived through the results in Section 6.2, are certainly relevant and discernible in the two clusters studied. The problem rather lies in that the picture is incomplete and missing evidence that can limit its usefulness. An index by nature is an aggregation of average measures of particular phenomena that can mask subtle but important dynamics (Shah et al., 2013). This can lead to conclusions that overlook critical local socio-ecological interdependencies and subsequently recommendations for reducing vulnerability that are not entirely mindful of the effects remedial actions can have on the land (McDowell et al., 2016). It is in the context of this difficulty in translating the intricacies of agriculture and livelihoods that the qualitative analysis is included.

6.4 Expansion of the index: A qualitative vulnerability assessment

In the qualitative analysis conducted in the remainder of this chapter, the goal is to understand the many varieties of farming, social dynamics, and market-relations that exist and govern vulnerability at multiple local scales, that are typically concealed in vulnerability assessments (Bernstein, 2010). In the following sections, the assumptions and indicators chosen for vulnerability assessment are re-examined and re-interpreted using local knowledge of the linkages between livelihoods, agriculture, technology, culture, and the social and institutional networks that lie behind the picture drawn by the AgLiVI. The analysis presented in the remainder of this section draws largely upon information from the household questionnaires (n=163), group discussions (n=4), case histories (n=10) and observations. The framework developed seeks to make the analysis representative of what was discussed in the field whilst keeping in mind broader applicability. Thus, community perceptions on vulnerability are presented in line with the IPCC guidelines of sensitivity and lack of adaptive capacity (IPCC, 2014). The hope is that the framework while remaining contextual can also be applied in other drylands across the Global South.

6.4.1 Framework for qualitative assessment

Communities largely consider themselves to be 'vulnerable' as a result of a set of their personal circumstances. Respondents were invited to talk about the different forces driving their vulnerability: Did they feel vulnerable? Why did they feel vulnerable? How does this impact on their use of land, water, and biomass resources?

Despite geomorphological, socio-economic, and cultural differences within and between the two clusters, four major vulnerability categorisations emerged from the field study, which are classified according to sensitivity and lack of adaptive capacity (Table 6.5). The categories described in Table 6.5 for analysing vulnerability were devised keeping in mind the dryland agro-ecosystems of Jodhpur, and are explored below.

Table 6.5: Categories for qualitative vulnerability analysis

IPCC factors	Categories to evaluate vulnerability	Questions of concern for communities
Sensitivity	Sensitivity thresholds of land, water, biomass resources	➢ Have they been breached? ➢ What indicators demonstrate this?
	Sensitivity thresholds of society and institutions	➢ Have they been breached? ➢ What indicators demonstrate this?
Lack of adaptive capacity	Reliability of access (to resources and support services)	➢ How dependable is the access? ➢ What is the quality of access?
	Sustainability of adaptive capacity	➢ How 'sustainable' are their adaptive capacities? ➢ How flexible are their adaptive capacities?

Sensitivity thresholds of socio-ecological systems (land and society)

Persistent changes in climate, markets, and socio-economic developments have threatened land systems and social systems such that they have reached or are close to reaching what communities refer to as a 'limit' or 'threshold', beyond which systems may be altered. A majority of respondents believe that their land is fragile but resistant; for instance, soil fertility and capability is low but suited to certain crops and types of cultivation; and social systems are characterised by vibrant cultures and social customs built on strong cohesion, and inter and intra-household relationships cultivated out of a need for sharing limited resources. A lack of engagement with the element of understanding the 'threshold of sensitivity' is a key gap in the practical utility of vulnerability research. In Chapter Two (Section 2.4.1), discussions showed that there is currently limited literature on vulnerability as a threshold[101] (Joakim, 2013). The reason vulnerability discourses shy away from identification of thresholds is likely due to the difficultly in defining threshold capacities, and measuring whether or not they have been crossed (Jurgilevich et al., 2017). This refers to thresholds that delineate harm or change, beyond which a system suddenly converts to a new state (Robinson et al., 2015). Literature is replete with classifications of boundaries and thresholds of various resources including land, which are typically conducted at a global scale. For instance, Carpenter et al., (1999) in a study of vulnerability to eutrophication, define the crossing of a threshold of a lake as moving from clear water to turbid water. Rockström et al. (2009) indicate planetary boundaries and tipping points for natural resources. Similar thresholds for social systems have been more difficult to define. Eakin and Luers (2006) argue that, other than the use of economic viabilities such as income thresholds, defining social thresholds can be complicated due to the differential risk and subjective variance within human populations.

While such concerns have validity, in this study, the concept of sensitivity thresholds has emerged from insights provided by the communities. Thresholds are thus simply defined according to the local context within which they are set, and are described here as expressed by the respondents themselves. The analysis therefore focuses on the sensitivity thresholds of both land and society. This provides significant benefits through enhancing the understanding of how communities perceive sensitivity, how it can be measured, and whether it changes or alters the ecological or social system state. Further, defining sensitivity as a threshold allows for the identification of 'hot-spots' (Jurgilevich et al., 2017) and to prioritise adaptation strategies that build on existing local knowledge (Hesse et al., 2013). For example, it has the potential to identify locations that have crossed the threshold of sensitivity arising from drivers, such as a decline in groundwater quality and quantity. This can add value for decision makers.

Reliability of access

The lack of access to services, resources, institutional support mechanisms, and markets decreases a household's capacity to adapt and therefore increases household vulnerability (Cutter et al., 2009; Shah et al., 2013; Tschakert et al., 2013). However, as noted earlier, in addition to incorporating 'presence' and 'availability' of assets or services, there is a need to determine whether factors governing access allow for 'true' and 'reliable' access. For instance, in the study area, it was evident during the field research that many households have had a water pipeline for many years but are yet to get good quality and regular access to drinking water. Similarly, a number of respondents had been given a MGNREGA employment card. However, only a few households had participated and benefitted from the actual works. In the

[101] 'Threshold' refers to the point where the system is sufficiently affected to show modifications.

AgLiVI, provisions are made for these issues. For instance, MGNREGA is only given a value in the index, if a member reported regular employment (i.e. if at least part of the requisite 100 days of wage employment was completed anytime over the last two years).

In addition, it was found that 'access' in the region is governed largely by the social location of a household in comparison to others. A household's social location can differ based on caste (despite the presence of community grazing land, a *Bishnoi* household in a *Rajput* dominated village will not get reliable access to most CPRs); income (a Below Poverty Line[102] card holder family is less likely to get institutional credit over a rich *zamindar*); gender (households with women in charge are largely ignored by the panchayat). Access to resources and support services therefore needs to be re-examined with a critical eye, viewed through the perspectives of communities, rather than traditional developmental notions of access. A community-based perspective on access will provide a richer understanding of the intricacies governing the existing lack of adaptive capacity already identified through the AgLiVI.

Sustainability of present adaptive capacities

The theme of sustainability is at the forefront of vulnerability research, due to the focus on promoting better synergies between human-environment systems. However, despite being strongly rooted in sustainability science (Turner et al., 2003), there is little knowledge of how to engage with sustainability principles within vulnerability assessments.

A number of authors have identified the issue that indices only capture current vulnerability, for a given time; the premise being that vulnerability indicates a certain state and less so the possibility of a future state, or change in state. Research addressing the forward-looking aspect of vulnerability works on the assumption that the envisaged future may or may not happen, thereby instilling uncertainty in the results (Hinkel, 2011). Detailed scenario-based assessments of vulnerability are not widespread, largely due to the presence of radical uncertainty and also because many of the issues facing vulnerable populations and landscapes are already in need of urgent current solutions. There are thus ambiguities in the scientific understanding of the dynamic nature of vulnerability, in particular, how current vulnerability impacts on future sustainability (Hinkel, 2011; Jurgilevich et al., 2017).

In this study, the assumption is made that even in considering current vulnerability parameters, it is important to take account of those attributes that make societies sustainable or unsustainable. As the ecosystem services framework that defines land degradation suggests, livelihoods are ultimately dependent on ecosystem services derived from stocks of natural

[102] Below Poverty Line benchmarks are relatively unclear in India. It is typically calculated using 13 socio-economic indicators that highlight the quality of life, and income and food security.

capital. In turn, a sustainable livelihood must therefore maintain critical stocks of natural capital (Ekins, 2003). This suggests that to assess the viability of adaptive capacities, it is necessary to determine whether they threaten critical levels of natural capital and the long-term viability of associated ecosystem services (Reed et al., 2013).

The concept of sustainable development while interpreted in many different ways, essentially rides on the following key premise – development that focuses on the present without compromising the ability of future generations to meet their own needs (UN, 1987). This is especially important in drylands, where development planning needs to be cognisant that current capacities are not exacerbating conditions (degradation of land and water resources) for the future. In the context of the dryland agro-ecosystems of Jodhpur, there can in effect be a vulnerability framework that focuses on current capacities to adapt, without ignoring future generations.

Overall, the four sub-components identified in Table 6.5 form the guidelines within which the qualitative vulnerability assessment is carried out. Within each of these components, discussions cover a range of crosscutting issues including gender, food security, tenure security, migration, caste and institutional support mechanisms. The analysis conducted in the subsequent sections will demonstrate connections between vulnerability, land use and land degradation, as conceptualised in the conceptual framework of assessment (Figure 4.2).

6.4.2 Sensitivity threshold of land and allied resources

The potential value of using 'thresholds of sensitivity', in the context of vulnerability assessments is discussed in Section 6.4.1. This section analyses the sensitivity thresholds of socio-ecological systems, as perceived and communicated by respondents in both clusters.

Sensitivity of land resources: Constrained by the region's bioclimatic and environmental limitations, sensitivity of land and related water and biomass resources to potential hazards or stressors is high in Jodhpur's drylands. On the other hand, thresholds are also high, as demonstrated by the ability of land to sustain high populations and livestock densities as well as biodiversity in spite of the significant limits and pressures placed on the land (see Chapter Five). However, in recent times, dryland degradation and climate change are presenting unprecedented challenges on the land, increasing its sensitivity to a level whereby communities perceive that the threshold has been crossed, and the land is now in a new system state.

A quote from respondent I_KB4 illustrates how communities perceive the changing sensitivity of their land, and the impact it has had on altering a system state beyond its threshold capability.

"*Considering the intensity with which we till and plough through the sandy loose soil, use urea and DAP, buy and apply more manure on smaller pieces of land, both land quality and land productivity should be much higher than they currently are. The land is now different than it was before, when we used to plough with animals. The soil was more compact and better able to retain moisture over longer periods*".

The view that the sensitivity threshold of their land has been crossed, and the land is now in a modified state that is less stable and more sensitive to any changes is shared by many respondents and it is linked closely with land intensification. The use of tractors to plough the land has replaced the traditional labour-intensive use of draught animals, such as camels and bullocks for tillage. In both clusters, deep tractor ploughing and the use of various tillage implements like a disc harrow, have increased. As discussed in Section 3.4.2, tractors were introduced into Jodhpur's agrarian landscapes almost 30 years ago, during the Green Revolution. It enabled larger farmers to be more efficient in cultivating their land. Tractors are now commonplace in the villages visited; even small and marginal farmers use tractors to till the land, renting them from larger farmers (a day's rent is around 30 USD). Some of the implications of the increased reliance on agricultural implements on the quality of land have been detailed in Chapter Five. To summarise, in both clusters the concern was that the significant increase in tractor driven tillage is not in line with a proportionate improvement in land quality or land productivity.

Respondents in Cluster I perceive that the sensitivity thresholds have been crossed primarily due to increased land degradation, while in Cluster II the respondents perceive changes due to diminished crop productivity. For instance, in Cluster I, land previously under cultivation is now under long fallow due to degradation. Respondents also stated that even when more manure was applied on the same plot of land, the quality of soil remains poor in terms of moisture retention and compaction. In the irrigated croplands of Cluster II, respondents highlighted that the land was 'not strong enough' to grow crops that were common 5-10 years ago, including cumin, red chillies, and isabgol husk. A primary *rabi* crop in Cluster II is now carrot, due to its ability to grow in sandy, loose and moisture-stressed soil. While farmers show an ability to adapt and remain flexible with their cropping patterns, their vulnerability lies in the uncertainty presented by climate variability coupled with a shift in the structural integrity of their soil. A respondent (II_J5) in Cluster II stated:

"Both the increasing variability of climate and continuous and intensive cultivation have managed to alter the physical and chemical balance of our soil, so much so that we do not recognise it anymore. My father will tell you the soil is completely different now from his time'.

This quote reinforces perceptions of the modified state of the land, whereby it is in a less recognisable state to the farmer. This evidence is supported by some sparse experiments published in the region, such as Tsunekawa et al., (1997) and Kar (2014a) that examine the negative influence of continuous cultivation and drought on soil properties affecting crop productivity in the Thar desert.

Overall, degradation of land is discernible through an increase in its sensitivity to hazards, to an extent whereby thresholds have been crossed and the land is in a new system state. This new system state is assessed by communities through a reduction in both potential of the land (in terms of crop productivity) and reduction in the quality of the land (increased degradation).

Sensitivity of groundwater resources: The mean annual rainfall in the district of Jodhpur is 323 mm/year, and is increasing in variability (Chapter Five); perennial sources of surface water are also absent in the two clusters. In light of this, irrigation has become a crucial lifeline in maintaining livelihoods in Cluster II[103]. However, the use of irrigation in an area with poor quality and quantity of groundwater has led to significant problems both for the health of communities and their land resources. Chronic ingestion of highly saline water has led to long-term health problems for many respondents. Common health concerns in the region include dental fluorosis especially among children, and skeletal fluorosis (which leads to an inability to walk) (Misra & Mishra, 2007; Mor et al., 2009).

Table 3.3 showed the extent of groundwater exploitation in the district. The sub-district of Osian, where Cluster II is located has a net groundwater balance (MCM) of -129% with respect to recharge (CGWB, 2013). The discharge of water in many of the wells in Cluster II have declined due to a slow recharge of natural aquifers. Table 6.6 illustrates the extent of abandoned wells (66% of total wells) counted in Cluster II; which is a huge loss in investment. Wells are now dug as deep as 1500 feet, while five years ago, the average depth of a well was around 300-500 feet.

Table 6.6: Number of abandoned tubewells in irrigated Cluster II

Cluster II villages	No. of working tubewells	No. abandoned tubewells	Total No. of wells
Rampura Bhatiya	43	112	155
Chaupasani Charnan	24	65	89
Jheepasani	14	15	29
Bhawad	14	26	40
Ujaliya	24	14	38
Total	**119**	**232**	**351**

Quotes from respondent II_RB1 and II_Jh5 highlight the implications of high economic costs of installing and running a tubewell:

[103] In Cluster I, of the households interviewed only four respondents had recently invested in irrigation technologies but since they had not started their first irrigation in *rabi* season yet, no information on groundwater sensitivities was available for Cluster I.

*"Often water drawn from greater depth is of poor quality and heavy (*due to salt content*), which impacts negatively on soil and crop yield, making the input costs of a tube-well higher than the benefits. As we dig deeper for water, the energy costs of drawing water increase, which needs to be compensated by switching to high-value crops to ensure return on investment".*

*"As my (*input*) cost of irrigation becomes higher, and the village tankas (*aquifers*) dry, we have had no choice but to either shift back to rain-fed cropping, or to leave agriculture for other sources of livelihood".*

As the quotes indicate, in addition to the implications for the future of irrigated agriculture in the region, there are large economic costs involved. Evidence from both primary and secondary data show that groundwater degradation in both clusters is now high, with both quality and quantity of groundwater significantly altered. This is indicative of a rise in sensitivity of groundwater to an extent whereby a threshold has been crossed, and the state of groundwater is in a new and less utilisable state.

Sensitivity of biomass resources: Biomass resources (grass, tree fodder, agricultural residues, and food grains) are under significant stress in the two clusters. Ever-increasing biotic and abiotic pressure and associated demands have damaged the traditional balance of agro-forestry systems in the region (Tewari et al., 2007). Studies have shown that indigenous species such as *P. cineraria* (*khejri*) and *T. undulata* (*Rohida*) are nitrogen-fixing trees and provide benefits due to their soil enrichment potential, contributing to improved crop yields and the provision of high quality feed for livestock (Singh & Pandey, 2011; Tewari, 2016; Tewari & Singh, 2006). On the other hand, trees and shrubs with shallow root systems including non-native species such as *P. juliflora* negatively impact on the yields of key crops grown in their vicinity (Tewari & Singh, 2006), as they compete with crops for soil nourishing nutrients and moisture. The large-scale spread of the invasive *P. juliflora*, is particularly relevant to this study due to its implications on altering the biomass landscapes of the region. Respondent II_Uj9 stated,

"Roots of trees in the desert need to be deep, so that they don't compete with our crops for manure, fertilizers and moisture. The roots of the khejri and rohida trees are deep, but Angrezi babul (P. juliflora) is very shallow. We have to remove the Babul, with tractors, two or three times a year, since it multiplies on the farm. The only use for this babul is fuelwood".

As indicated in Chapter Four, indigenous tree species are more abundant in Cluster I, with every household owning around 40 trees of multiple species (e.g. *khejri, rohida, ber, desi babul*) on average on their farms and homesteads. In Cluster II indigenous trees on farms and homesteads are fewer in number (10-15 trees of *khejri*, *rohida* and *neem*). This is largely because most trees have been cleared for irrigated croplands. The growth of the non-native *P. juliflora* has been higher in Cluster II and requires regular clearing as indicated by respondent II_Uj9.

The increase in *P. juliflora* has been associated with the loss of indigenous range grasses such as *C. ciliaris* (*dhaman*) that have significant horticultural and pastoral value (ibid.), due to their use in forage. Importantly, Tewari and Singh (2006) in their study show that both grain and fodder yield of pearl millet is enriched alongside local grass species of *dhaman*. These native range grasses are well adapted to flourish under the native *khejri* in comparison with the non-native *P. juliflora*. Experiments show that under the *khejri* tree, range grasses in the Thar Desert increased production by 2.3t dry matter/ha/yr, whereas under *P. juliflora*, production of these important range grasses decreased (ibid.).

In addition, the increased population of livestock and dependence on CPRs and overgrazing on the same pasturelands have led to a significant decline in the quality of CPRs in the region. Pastoralists in the Thar Desert are traditionally nomads, travelling with their livestock throughout the region with the purpose of not intensifying use in one particular area. As discussed in Chapter Five (Section 5.6.3), a majority of nomads have shifted to sedentary livelihoods and pressures on nearby pasturelands have increased.

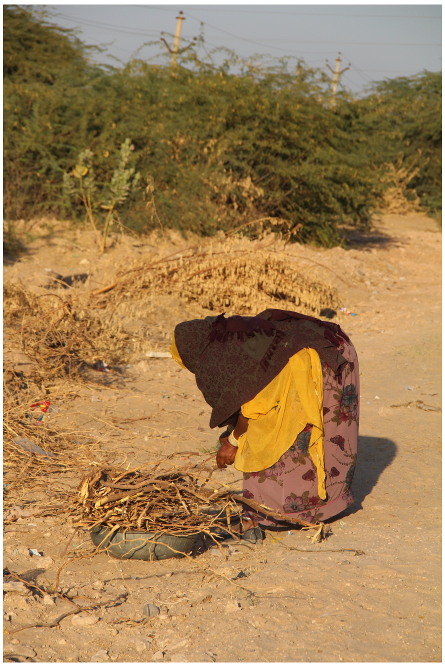
Therefore, there is sufficient evidence to show the increased sensitivity of biomass resources, where the landscape has been marked by changes from indigenous species to non-native, and often invasive species. These have led to a shift in the biomass landscapes of the two clusters, indicating a threshold has been crossed.

***Prosopis juliflora (P.juliflora)*: Untapped benefits**

There is an alternate view on how *P. juliflora*, now a primary tree in the region can contribute benefits that have gone untapped. While respondents communicate the negative implications of *P. juliflora* growth on their fields, scientists highlight that the tree and its products can be invaluable to the sustenance of arid regions. *P. juliflora*, belongs to the family Fabaceae. It is native to south and central America and is able to thrive even in the harshest arid conditions. It was introduced in India around 1870 as part of the re-greening efforts by the then king of *Rajputana*. The species is prone to spread like a weed and has populated many parts of the Thar desert. There have been clear adverse implications on agro-biodiversity loss and negative impacts on crop yields.

On the flip side, respondents, especially in Cluster I acknowledge that they are entirely reliant on *P. juliflora* for fuelwood. They believe that increased growth of *P. juliflora* has helped prevent the cutting of more useful species such as *khejri* and *rohida* for fuelwood As their cropping seasons become increasingly unstable, respondents in Cluster I revealed that they are grateful at times for this 'invasion' of *P. juliflora*. Furthermore, scientists' argue that though the tree cannot be entirely eliminated from the desert, it can be put to interesting use, such as the use of *juliflora* pods for livestock feed, to make coffee, and charcoal from its wood (Tewari et al., 2011). Significant research is needed to establish the value-added benefits of these products, and there is currently a lack of communication in delivering knowledge about the benefits to local communities.

Picture 6.1: *P. juliflora* grows across village boundaries and is the primary source of fuelwood in both clusters (left). Scientists are looking for unique ways to use pods of the plant (right)



Source: Author's own

In summary, evidence shows a shift in the land, water, and biomass systems into new system states that are increasing their sensitivity to hazards or stressors. This is also supported by analysis in Chapter Five and related studies in the region (Chinnasamy et al., 2015; Kar et al., 2009; Tsunekawa et al., 1997) which highlight altered soil ecology, over-exploited groundwater levels, and the presence of non-native tree and grass species.

6.4.3 Sensitivity of society and social networks

As discussed in Section 6.4.1, social thresholds of sensitivity are difficult to define and measure. Through discussions in the field, three important themes of social sensitivity emerged and each are discussed in depth:

1) Social networks and informal relationships
2) Land fragmentations and transformation of the joint family
3) Education and its impact on social cohesion

Social networks and informal relationships: In Jodhpur district in particular and western Rajasthan in general, a variety of social groups relied on each other, in what was viewed by many as self-regulating (Malhotra & Mann, 1982), until the effects of changes in larger society disturbed these systems. Social cohesion, informal networks and relationships are often addressed in literature on social justice systems and informality, but are rarely acknowledged in vulnerability assessments (Jordan, 2015). In the AgLiVI, social dynamics are measured by the following indicators: the size of the household, the number of women in the household, the level of education, the level of skill, and their place in the traditional caste hierarchy. These indicators contributed 14% in Cluster I and 13% in Cluster II to the index.

During the field study, the complexity and significance of local social networks in managing the sensitivity of households was found to represent a key driver of vulnerability; differentiating a vulnerable household from a resilient household. Social relationships and networks, in these clusters, are more valuable than the ownership of assets - such as a pukka house or a private vehicle - typically considered important indicators of socio-economic standing in global development and vulnerability research (Gerlitz et al., 2016; Rajesh et al., 2014)[104]. For instance, households located close to each other in the isolated hamlets of Cluster I, collectively assess risk and sowing patterns. Women and children regularly partake in community-based activities together, such as lopping trees, foraging, livestock rearing, and cooking. In times of fodder scarcity, informal agreements are made where for example access to grazing pastures are provided by one farmer in exchange for goat manure on his/her fields. Due to the predominance of subsistence farming in Cluster I, information sharing and knowledge

[104] A pukka house or private vehicle are likely important in regions prone to risks such as landslides, flooding, and storms. In Jodhpur, however, pukka houses were not considered any more valuable than a traditional (kuccha) house. A kuccha house (made of mud and thatch) offers cooler refuge from the hot summers, according to respondents.

management is done through informal communications between households. Those with greater social networks are less sensitive due to the social safety net provided by collective support in times of need. As narrated by respondent I_NN10 in Cluster I:

"We need to keep our relationships strong, both with each other and with our land. When I lose my crops, I can rely on my neighbour; when I lose my neighbour, I can rely on my crop".

A number of these informal information and social networks have disappeared in Cluster II, in exchange for newer and more formal networks, such as land leasing, renting of tractors and tubewells. While these have their benefits, in their current form, they are dominated by rich ex-*zamindars*; they provoke distrust, contributing to the loss of both intra and inter-household relationships.

This shift in social networks is also accompanied by a shift in the values placed on key resources. A general observation by an elderly *Bishnoi* respondent in Cluster II was that people were far less sentimental about their trees. He stated (II_Jh5),

"Farmers have forgotten that our trees have been our saviours for many generation, they feel no mercy in chopping them down to make way for more cropland".

Respondents in Cluster I are more sentimental about their land, while in Cluster II respondents are more pragmatic. Trees such as *khejri* and *rohida* hold cultural and religious significance to the people of Rajasthan, especially to certain caste groups such as *Bishnoi* (a number of whom live in Cluster II). Clearing of these trees to make way for cropland has led to a number of small but violent conflicts in some of the villages, such as *Ujaliya* and *Jheepasani* in Cluster II, driving a wedge between the large *Bishnoi* population and other castes and religious communities.

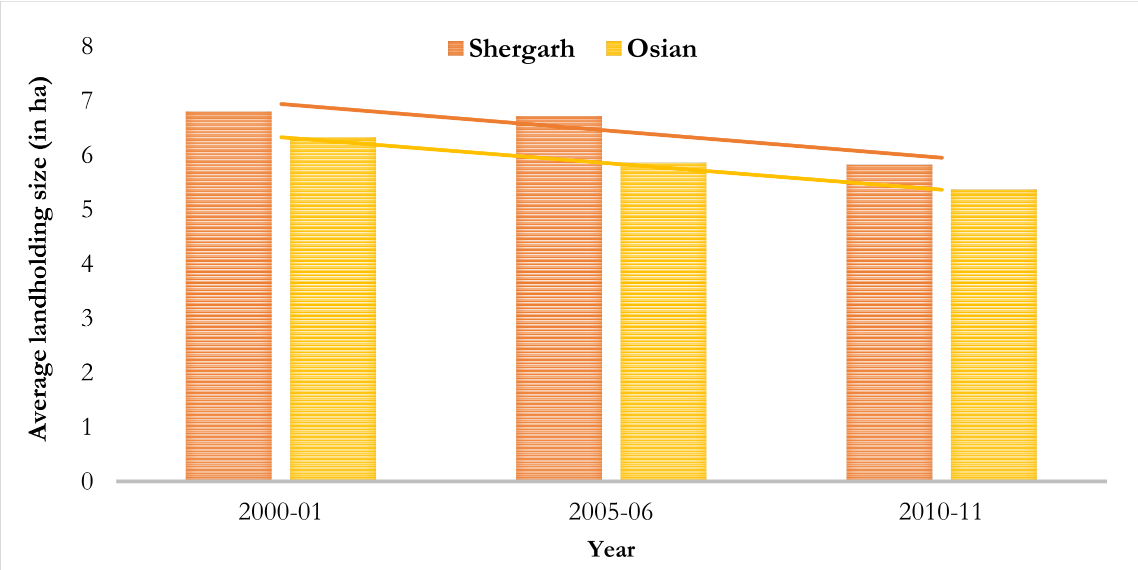
There are also fewer community based activities in the villages of Cluster II, and respondents in a focus group (II_FC1) provided a reason,

"Intensive farming requires more time in the fields, which leaves us with less time for ancillary activities and socialising, which used to be a key part of our day in the olden days".

This quote represents how technological transformations leading to newer social systems have changed community and cultural identity. It demonstrates that in regions where livelihoods are closely linked to their agro-ecosystems, any changes in these ecosystem functions and services, will affect social cohesion and dynamics. There is sufficient evidence from Cluster II to show that once altered, and locked-in, significant effort is required to bring social structures back to a cohesive structure built on trust and equal distribution of resources.

Land fragmentations and the loss of the joint family: The fragmentation and sub-division of land-holdings have led to significant alterations in the way land is used and society has organised itself (Ram et al., 1999; Salvati & Zitti, 2009a). In Jodhpur, the shrinkage in the average size of operational landholdings is a result of population growth, and tenancy laws of the 1950s, where equal share of the parental property was conferred to each male heir[105]. Tehsil level information from India's Census (2011) shows average individual landholding size in the two tehsils (see Figure 6.7 below). In Shergarh, where Cluster I is located, average landholding size over a ten-year period (from 2000-2011) fell from 6.7 ha to 5.8 ha. In Osian, where Cluster II is located, average landholding size fell from 6.3 ha to 5.3 ha between 2000-2011. In Cluster II, smaller families are more prevalent, indicative of the loss of intra-household relationships.

Figure 6.7: Individual landholding size (in ha) 2000-2011 for Osian and Shergarh tehsils



Source: Derived using data from Agricultural Census of India (2011)

These land fragmentations in turn have led to a breakdown of the 'joint family' in the region. Large joint families are a characteristic of traditional Indian society (D'cruz et al., 2001) and are particularly established in Jodhpur, where they represent an important risk diversification strategy[106]. Large joint families, generally considered in development theory to be vulnerable due to the 'more mouths to feed' theory (Brenkert & Malone, 2005), were in fact considered a resilient attribute in the study area; the more people in a household, the more hands available to perform agricultural and diverse livelihood tasks. Land fragmentations have in effect led to smaller households and fewer family members, signifying a loss of traditional collective risk-

[105] In dividing the land between the various male heirs to evade land ceiling laws (where one land-owner was prevented from owning more than a certain amount of land), most families split their landholdings into equal small portions, which in turn were split into smaller portions for the succeeding generation. Eventually this led to families splitting from joint to nuclear families.

[106] Joint families comprise of a couple, their unmarried children, their married sons and their families, all living together under one roof and owning and performing agriculture and livelihood tasks together.

sharing strategies. The shift from joint to nuclear families has also impacted intra and inter-household relationships, prompting property disputes and distrust amongst large families.

Land fragmentations have also led to changes in agricultural strategies, which have in turn impacted on the sensitivity of land. The first implication of smaller landholdings is an increase in the proportion of cropped area and a decrease in the proportion of land under fallow (Source: II_FC2). Area under current fallow is almost non-existent in Cluster II, whereas two generations ago it was at least 50% of their agricultural land (Source: II_FC2). Decreased fallowing leads to a reduction in the concentration of available phosphorous in the surface soil, crucial for maintenance of land health (Ram et al., 1999; Tsunekawa et al., 1997). A second implication of smaller landholdings has been shifts from mixed to mono-cropping (Ram et al., 1999). 75% of households interviewed in Cluster I and only 10% households interviewed in Cluster II, partake in mixed cropping. Mixed cropping, where pearl millet is sown alongside pulses, such as mung and moth bean, restore soil and improve yields, through nitrogen fixation (Joshi et al., 2009; Zampaligré et al., 2014). Mixed cropping however involves more labour-intensive farming techniques in both sowing and harvesting, which the smaller nuclear families of Cluster II are less able to undertake.

Overall, a loss of social cohesion and informal social networks, especially in Cluster II, are indicative that transformations in social systems have led to an increase in the social sensitivities of farmers in the region. In some cases, they have led to entirely new social systems (such as in Cluster II) that are less reliant on social networks and more on individual capabilities.

Education and social cohesion: Literacy plays an important role in reducing vulnerability because it drives the ability to: access and assimilate information; understand and adopt new technologies to benefit land without exacerbating degradation; participate in local governance and most importantly benefit from government programmes; and access different sources of income (Alwang et al., 2001; Cutter et al., 2009). Education is also critical in improving notions of self-worth within a community (Singh, 2014).

Education levels in both clusters are poor; only one member per household (on average) currently attends secondary school. Education of women is especially poor in both clusters; most women do not attend even primary school. The government makes sufficient provisions for children, especially girl children to attend both primary and secondary school, but attendance rates in the villages studied were low[107]. Education, despite the benefits it offers in

[107] The state provides free and compulsory education to all children of primary and secondary school age (six to 14 years). In addition, to promote attendance rates in rural areas, free mid-day meals are provided and free cycles to girl children to travel the long distance to secondary schools.

its end goal of providing skills, was rarely brought up in interviews as something of consequence to respondents. Two quotes represent perceptions on the (lack of) value given to education in reducing household vulnerability:

"I understand that education will add a lot of value to my life but for education to pay off, I will have to study not just primary and secondary school but till college, which is unlikely since I will not be able to afford it. Even if I do end up in college, it will only pay off if I leave the village and seek employment in the city. All the educated people leave the village. So, I will not find any use for it in my village, where I want to stay".

"My parents force me to attend school. I hate going to school, they don't teach me anything of value. What am I going to do with chemistry, biology, and physics? I need to learn how to manage the land, how to skin the wool off our sheep, and how to pluck the seeds off the khejri. I want to stay at home with my mothers, aunts and sisters. They play with the goats all day, they run around trees and they help out in providing food for the family. That is what is more useful for me".

As illustrated by the first quote - an adult male (II_Uj7) - it was found that most educated farmers choose to leave the village to pursue opportunities in the city. The second quote – a young adult female from household (I_NN3) - illustrates that the benefits of a formal education are not valued or recognised, due to perceptions that the taught curriculum does not integrate well with their current livelihoods.

Overall, at first glance, households in Cluster II appear to have lower social sensitivity due to the trajectories of transformation and innovation brought on by closeness to the city and market-driven growth. The developmental trajectory of households in Cluster I, appear to be more static and less able to integrate alongside national and global trends. However, the analysis conducted here shows that respondents in Cluster I have stronger social systems that offer support, informal connections, and management strategies. These informal connections are rarely incorporated in vulnerability assessments, but do in effect reduce their sensitivity to changes.

6.4.4 Reliability of access

A number of government-led rural development programmes have improved livelihood support services in rural Rajasthan. Key services such as piped water and electricity are now available in these villages, improving their adaptive capacities. The AgLiVI presented in Section 6.2 measured access through indicators such as the presence of a road (*pukka* road); fuel (presence of LPG); sanitation (toilet); access to drinking water (piped water access); loans (formal and informal); and government programmes (participation in MGNREGA employment). There still exist gaps in provision, a few are included in Tables 4.3 and 4.4.

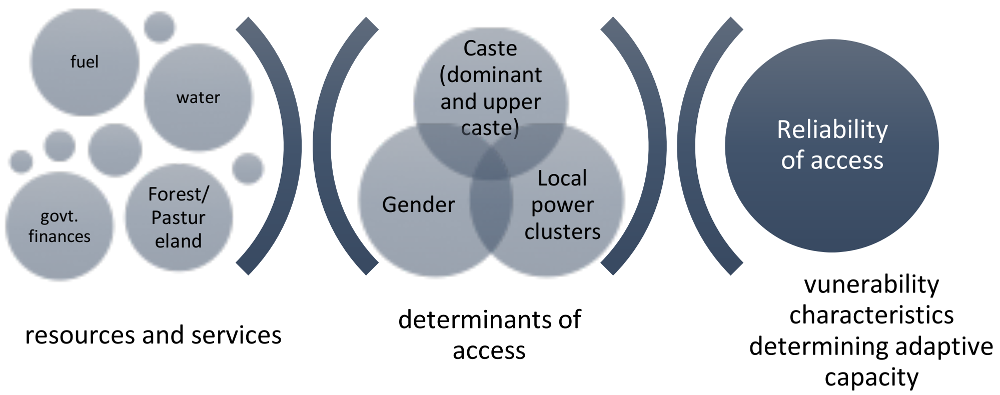
Access to resources, support and extension services at a ground-level are driven by three key power hierarchies (illustrated in Figure 6.8) and the politics within each: (i) the caste hierarchy;

(ii) local power clusters (prevailing *zamindari*-system politics); and (iii) gender. The significance of each in determining capacity to adapt is discussed below, keeping in mind two characteristics:

- Is the access reliable?
- What is the quality and extent of access?

Only factors that have had a significant impact on vulnerability and land degradation have been considered for discussion. Factors such as health and sanitation, while important, were not mentioned as significant limitations to livelihoods within the two communities studied. It was therefore difficult to incorporate discussions on health within the scope of this qualitative analysis[108].

Figure 6.8: Politics of access



Source: Author's own

Caste

The strongest identity people have in this region is their caste and faith. Caste is one of the main social factors that impacts on a particular household's access to and use of resources and any study of vulnerability in the region needs to take caste dynamics into consideration. The traditional view of caste is a single hierarchy from Brahmin (uppermost caste in the Hindu caste ladder) to 'untouchable' (lowest caste) (Dumont, 1970), and is described in Chapter Three. The field study found that positions in the traditional caste hierarchy while present have been re-defined by evolving markers i.e. 'dominant' or 'pioneer' caste[109] (Debnath, 1995; Smith, 2005). For instance, the village of I_KB in Cluster I was dominated by *Kumhars* (translates to potters), the pioneer caste in the village, traditional potter communities who are classified by the government as 'other backward class' *(OBC)*. Instead, in I_KB, they were found to have

[108] Questions on health were in the interview guide, but it was soon clear that respondents were either not comfortable speaking about health or simply that health did not have significant implications on either sensitivity or adaptive capacity. The importance of suitable access to health and sanitation is not entirely missing in this thesis. Sanitation is incorporated in the AgLiVI as an indicator. Further, where health issues were brought up, they are included in the analysis.

[109] Pioneer caste is typically formed of early settlers in the village. They were followed by their brethren and now form the dominant caste population of the village.

significant power in their village, more so than *Brahmins*, who are traditionally, upper-caste Hindus. The position of a particular household within this new, dynamic caste hierarchy in turn determines their ability to access key resources and services that help strengthen their capacity to adapt, reducing vulnerability.

Caste determines the distribution of houses, and maintenance of inter and intra-household relationships. Typically, the Gram panchayat[110] leader or chairman (locally known as *sarpanch*) controls the distribution and access to public resources and services. The *sarpanch* is democratically elected and typically belongs to the dominant caste of a village. In the case of Khari Beri in Cluster I, the *sarpanch* belonged to the dominant caste of '*Kumhars'*. Adding another layer of complexity, traditional upper caste Hindus such as, *Brahmins* and *Rajputs* in Rajasthan, always have more clout within the community than someone belonging to a lower caste, especially SC/ST (e.g. *Meghvals*). Three prominent examples of how caste determines access to services are given below:

- **Politics of Caste and its impact on access to Liquefied Petroleum Gas (LPG):** In rural India, subsidised gas (LPG cylinders) are provided to improve the energy security of the poorest households However, respondents in both clusters indicated that before LPG cylinders reach them, those in power misappropriate them, and eventually distribute them illegally and informally to households belonging to the dominant caste.
- **Politics of caste and its impact on MGNREGA:** As mentioned before, MGNREGA is one of India's largest rural development programmes, aiming to provide social security to India's rural poor by providing 100 days of guaranteed waged employment to every rural household. The selection works for MGNREGA is given to gram panchayat, who in turn are meant to allocate the work and ensuing wages to the intended beneficiaries, who are small and marginal farmers, landless labourers and women (Carswell & De Neve, 2014; Esteves et al., 2013). In both clusters, MGNREGA works were first prioritised to those belonging to the dominant caste, irrespective of whether they needed the work or not. In addition, members of this dominant elite were found to not participate in the actual works, instead substituting another person to sign for them instead while they receive the payment. This misappropriation of MGNREGA work was reported particularly in Cluster II. Although some misappropriation of funding was reported in some villages in Cluster I, respondents were largely in agreement that work should be distributed according to availability and need, due to stronger community cohesion in the widespread remote hamlets of Cluster I
- **Politics of caste and Public Distribution System (PDS):** PDS is a targeted food security system, where food grains like wheat, sugar and some non-food items like

[110] See Chapter Three for a structure of the panchayat

kerosene are distributed in a certain fixed quantity per head to the public at a subsidised cost. Set up mainly to benefit the poorest households and vulnerable communities such as members of SC/ST households, food rations are distributed primarily through an elaborate institutional arrangement comprising state and district level officials, wholesalers and retailers. Respondents in both clusters reported not getting their ration every month, and in some cases, households were denied their monthly entitlements. This was largely due to vested interests of dominant caste members who influence the system. The lack of transparency in quota and ration distribution and corruption at all levels of PDS has been an ongoing concern for the government, highlighted in monitoring reports and research articles (Khera, 2011; Rehman et al., 2005).

Similar misappropriations relating to the dominant caste was reported universally in the distribution of most government-sponsored programmes and schemes at the village level, including subsidised seeds and fertilizers. Households that belong either to the dominant caste of the village, or upper caste Hindus have 'reliable' access to resources and therefore have a greater capacity to adapt. Overall, despite the prevalence of many programmes and institutional mechanisms in place to help communities access key vulnerability-reducing services, 'true' or 'reliable' access is largely overlooked, and only extended to a particular set of households based on their position within the caste hierarchy of the village.

Local power clusters

The 'reliability' of access is also determined by the status of communities in the income hierarchy of the village. Positions in this hierarchy while largely related to caste have been re-drawn by other developments such as education, proximity to centres of power in the outside world, and economic circumstances (Smith, 2005). As will be evident in the discussion below, these also have significant implications for the way land resources are being used. An illustration of the impacts of this political hierarchy on a household's capacity to adapt is illustrated through a focus on land tenure, credit access, and pastureland deterioration, all key facets of vulnerability reduction in Jodhpur.

Land tenure and adaptive capacity: Historically, *khatedars* and *zamindars* in Rajasthan wielded maximum power in the village, especially over control of natural resources (Chapter Four). While the policy since Independence has attempted to shift land ownership to the tillers of the land, a number of influences from the early days still remain. Influential and politically well-connected farmers have been able to encroach upon large proportions of public lands, the process known as *kabja*, which is a sort of de facto privatisation (Gupta, 2016). This coupled with the growth and hegemony of the Green Revolution has led to many inequities in communities gaining reliable access to land.

The maximum impact of this hegemony was reported in Cluster II, where the advent of tubewells led to large-scale changes in land use and management of natural resources. These significantly affect smaller, marginal, and landless labourers in their capacity to access support. This insecurity in tenure arrangements has led to many farmers selling off their lands, and moving toward a system of land leasing. This was a burgeoning strategy used by many in Cluster II. Leased landholders are different from agricultural labourers. Leasees technically own the land they till for the length of the contract, and thus wield more power over choosing the quantity of inputs, cropping choices and harvesting techniques, while labourers only help in manual work, with no power in decision-making. While leased landholders and agricultural labourers commented that a lack of ownership over the land they till put them at the mercy of large landholders; a number of large landholders in turn commented on the negative impacts that the leased landholders have had on their land. A comparison of two distinct narratives is presented below, one of a large landowner/*zamindar* (II_RB7) and another of a leased landholder (II_RB6); where II_RB7 had leased a small portion of his land to II_RB6.

Views from a large landowner (Cluster II: II_RB7)

Landholding size: 500 ha

Both my sons work in the city, they have private jobs. I am growing old and need help to take care of my land. I lease land out in portions to 5-10 farmers every 2-3 years. Our leasees are typically small and marginal dryland farmers (whose land is left unproductive), landless labourers or farmers whose fragmented landholdings have left too little land to live off. They lease small pieces of land (between 2ha and 10ha) from us and use our tubewells for groundwater irrigation. The leasee contract typically lasts 2-3 years, after which the rent goes up. A majority of the leasee farmers therefore prefer to move on to a different landlord after 3 years.

The problem we have is that this short-term land holding pattern of our leased farmers means they are not invested in the long-term sustainability of the land they till. Therefore, short-term productivity being their aim, they use large amounts of fertilizers and chemicals (which end up 'burning' the land) and tilling the land more times than required. This leads to a cycle of bad land use management decisions. Sometimes when they hand over the land after two years, I have to leave portions of it fallow for many years after, so that some soil fertility can be salvaged.

I am vulnerable because my land is of poor quality and tillers (leases) are exacerbating degradation.

Views from a leased farmer (Cluster II: II_RB6)

Leased landholding size: 10ha

I am a leased labourer. My father used to own 5 ha land. Our family split and he gave all his sons 1 ha. I have a family of 15 who I need to feed and 1 ha of dryland is not going to do much to fulfil the basic needs of my family. I rent different parcels of land from larger landholders with tubewells in the village so I can irrigate crops, such as castor, cotton, and carrot which give good returns in the market. I change land every three years to a different location.

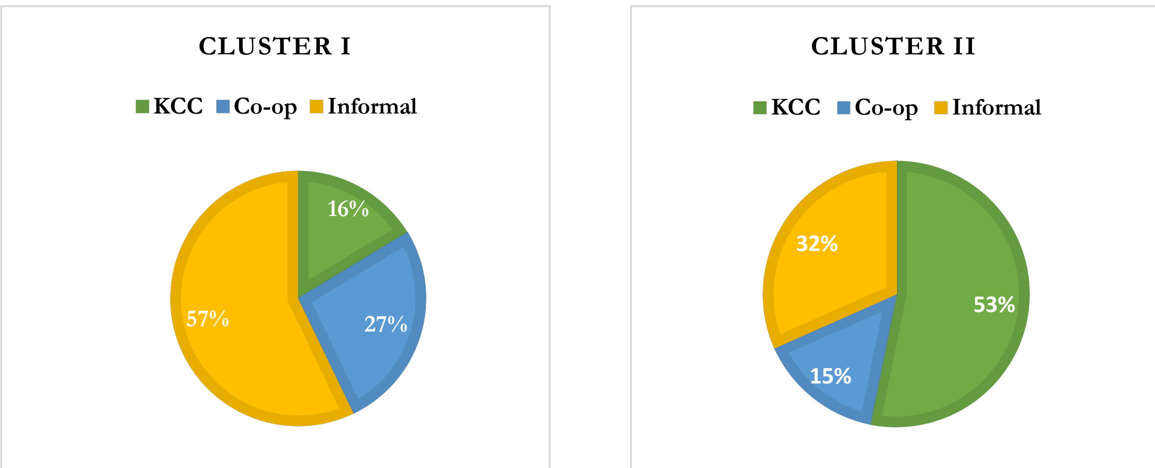
These rich people have monopolised our land and now agricultural productivity in the region. They charge exorbitant rents and if we can't pay up they lease us the land by informal contracts, where they can keep up to 75-80% of the returns from our hard work. In order to pay them, I need to do everything possible to get high *yield. I know the land itself is bearing the brunt of this but I am left with no choice. The land becomes infertile in two years, and then I have to move on.*

I am more vulnerable because I lack access to the land that I till.

The above comparative snapshots from Cluster II, help link the reliability of access to 'tenure' with vulnerability and behaviours that lead to persistence of dryland degradation. It demonstrates that local power appropriation and land fragmentations have led to tenure insecurity among small and marginal farmers. This lack of security has made vulnerable leasee farmers want to extract as much value as possible from the leased land so as to pay off the land owners in time. To do so, they tend to intensify crop production for short-term returns, exacerbating land and groundwater degradation in the long-run, in turn increasing their sensitivity.

Credit access and adaptive capacity: Access to credit is a factor that limits smallholder farmers in their capacity to adapt. Larger landholders have better access to institutional and formal credit sources. For instance, the Kisan Credit Card (KCC) scheme offers farmers in India access to affordable cash credit to buy seeds, fertilizers, pesticides, irrigation technology etc. Eligibility for the KCC is based on repayment capacity – which is turn is evaluated by the size of land holdings, availability of irrigation, and the income earned from it. Due to the eligibility criteria, a majority of farmers in Cluster I do not have access to KCC loans. They instead largely rely on informal lending schemes through local money-lenders. While in the short-term, informal lending offers benefits through provision of immediate access to credit during a crisis, in the long-term many end up in debt (pawning off jewellery, selling livestock, mortgaging land to pay off the high-interest informal loans). Some farmers reported using loans through a cooperative society, typically given to people with stronger social connections. A graph of credit facilities accessed by respondents is shown in Figure 6.9.

Figure 6.9: Access to formal and informal loans by cluster (% households)



There were some respondents who had not taken any loans, mostly the landless; they have no assets against to secure a loan. The lack of access to institutional credit reduces the adaptive capacity of farmers, since they may be unable to access seeds, fertilizers and other benefits.

Market access and adaptive capacity: Due to greater scales of production that demand market access, larger landholders were observed to have closer links with markets and all the ancillary benefits of market access. In Cluster I, most landholdings are scattered and located away from the village centres and main roads, reducing their capacity to access the markets. In Cluster II, despite its proximity to Jodhpur city (30 kms), road infrastructure is poor with a few bad quality roads connecting the villages to the main roads and highways. The need for markets (to sell yields) has led farmers in Cluster II to form their own network of access - a few farmers hire tractors and vans once a month, collecting their own produce in addition to produce of other neighbouring farms (at a prearranged cost), delivering them to the markets of Jodhpur city and beyond.

Market access was found to have important implications for food security and therefore adaptive capacity. In Cluster I where market access is low and agriculture largely for subsistence, close to 75% of households interviewed had small patches of garden or vegetable crops that make their food systems relatively self-reliant[111]. Their ability to self-organise and self-regulate while perceived by some within the community as a disadvantage (in comparison to others who had market access) can be a huge advantage. Small and marginal farmers interviewed in Cluster I did not report any severe hunger or deprivation, even during drought years. However, in Cluster II, self-sufficiency in growing their own food has been elusive. Respondents highlighted that they prefer to buy food from local markets, which reduces their self-sufficiency in times of crisis (such as increase in market prices during drought). Most small and medium-sized landholders in Cluster II reported hunger and deprivation during low rainfall years, indicative of lower capacity to adapt.

Pastureland deterioration and adaptive capacity: CPRs were exposed to high levels of degradation in both clusters. They are critical for the semi-pastoralists in the region, mediating their capacities to adapt. While no evaluation study in the region exists on management of pastures by village councils, respondents spoken to in all villages stated that there was little or no open pasture/grazing land left in their villages. A study of Census (2011) information reveals grazing land (of varying quantity) is allocated in two villages in Cluster I and all the villages of Cluster II.

[111] Many respondents in Cluster I indicated that they use the piped water they get once or twice a month to water their garden crops.

Table 6.7 illustrates comparative data, taken from the Census alongside quotes taken from respondents in each village. The absence of land tenure and the resulting lack of stewardship is a major constraint in gaining reliable access to the pasture land.

The quotes in Table 6.7 are illustrative of the complexities and layers of involvement by various local power authorities in governing access to CPRs in the region. Pastureland that existed even 15-20 years ago is either heavily degraded (with non-native species occupying large areas due to mismanagement and overgrazing), inaccessible due to illegal occupation, or sold to private industries. In Cluster I, farmers attribute the loss of CPR access to government policy, from as far back as 1952, where local panchayat leaders were given full control over these resources. In Cluster II, most CPRs have been encroached upon, as cropland expansions started to generate more income with the advent of irrigation. Both are narratives of local power appropriation.

As indicated in Chapter Five, newer policies on pasturelands promise to make governance over these lands more stringent, but are yet to be adopted. In the meantime, livelihoods in the region are changing, with a majority of pastoralists and semi-pastoralists now almost entirely reliant on crop-based farming, adding further stress on agricultural land and declining groundwater reserves. As discussed in Chapter Three and Five, the loss of CPRs has prompted a shift in livestock composition, from owning large numbers of camels, sheep and goats, to owning few cows and buffaloes, which are easier to stall-feed. Goats and camels are able to survive through water shortages and on the scantiest vegetation. On the contrary, respondents indicated that cows (and calves) are typically the first to be affected by drought or heat stress. A diverse composition of livestock provides alternate sources of food (milk and meat) and livelihoods in case of crop failure. Thus, reduced diversity in the composition of livestock is indicative of a loss in adaptive capacity.

Table 6.7: Access to pasture land according to Census 2011 vs. responses in study villages

	Villages	Pasture land (in ha) As per Census (2011)	Pasture land access as reported by respondents
Cluster I	Narayana Nagar	-	*After independence, there was a government survey conducted and all grazing land was given to the Panchayat. God knows what they did with it. We haven't had any permanent grazing land for decades.*
	Dhandhaniya Bhayla	15.15	*Pasture land is very far and is fully degraded (weeds and P. juliflora are the only things that grow there), lot of wild animals (Nilgai, black bucks, wild camels, wild cows) use it. I heard some government forest officials recently visited and planted some trees but we have to walk very far to reach the land.*
	Khetasar	-	*The pasture land we had was divided up a long time ago by the elders of the village. We had no say in the matter.*
	Chauthpura	-	*There is no pasture land in this village since my father's time, I have 100 sheep and 100 goats, I have to walk 10 hours a day to find some open grazing land. I leave home at 4 am and return around 8 pm.*
	Khari Beri	10.4	*We have some pasture land but I am (Rajput) not allowed to use it.*
Cluster II	Ujaliya	25.05	*Government has made it protected forest land, due to heavy degradation. It is overrun by P. juliflora, and weeds, so we can't use it anymore.*
	Bhawad	208.02	*Pasture area has lots of problems, (i) local rich folk are trying to make money by monitoring access (ii) it is not taken care of properly. I used to visit it but I felt there are too many cows and goats grazing there. Goats in particular are very bad for the vegetation, they eat up everything.*
	Jheepasani	1.11	*No land left now. The land was recently seized by IIT Jodhpur for its campus. I heard they want to also build a highway for access to Jodhpur city with it now.*
	Rampura Bhatiya	194.72	*Large landholders and tubewell owners have encroached upon a majority of our Gauchars (pasture lands). Most of it has been converted to cropland and any attempt to leave my sheep and goats grazing, lead to large-scale community fights. I had to sell all my sheep and goats because of this.*
	Chaupasani Charnan	1.17	*All our existing Gauchars (grazing lands) were converted to cropland. It has been illegally occupied by these tubewell farmers.*

Source: GoI (2011a) and household interviews

Overall, it is found that in addition to their position in the village caste hierarchy, the position of households within local power hierarchies is important. These are in essence rooted in the policies of the old *zamindari* system, whereby those at the top of this hierarchy have a discernible advantage in gaining reliable access to resources such as crop land and pastureland; in addition to governmental services such as credits. In the two study clusters, it is also evident that in gaining access, they also control how the resources are used, inadvertently changing the rural landscapes they live in.

Politics of gender

The patriarchal structure of Rajasthan's society ensures women are denied a number of basic human rights. In addition, women lack access to land ownership. For instance, of the 163 households interviewed, not one household was officially headed by a woman. Even when women have legal provision for heritable transferrable rights, they are denied it. For instance, a Hindu Succession (Amendments) Bill, passed in 2005, guarantees Hindu women in India equal rights over agricultural land and joint property in the Hindu Undivided Family (joint family) (Mishra, 2005). Equal inheritance rights continue to be met with significant social resistance. The custom of "*haq tyag*", or sacrifice of right (Chandran, 2016), is widely practiced in Rajasthan. *Haq tyag* is a formal ceremony, where a person – typically a woman – 'donates' (*thyag)* their 'right' (*haq)* to land.

Women in Rajasthan also face isolation from society and limitations on public participation, due to cultural norms placed on them, making them particularly vulnerable. A vignette given below illustrates a Muslim woman's problem with resource access, limiting her adaptive capacity.

Women farmer – Cluster II (II_JJ9)

Age: 25 HH: includes, 1 Adult male, 1 Adult female; 4 children (1 girl and 3 boys, all below the age of 14)

Land fragmentations in the region have become common. So, when her father-in-law split his land between his six sons, her husband was left with only 1 ha. They decided to move to the village of *Jheepasani* where they had heard that many rich landholders with good irrigation infrastructure had moved to city and were looking for farmers to live on and care for their land in return for 25% profits. Her husband suffers from a fluorosis (a debilitating disease from which 25% of the population in rural Rajasthan suffer, due to excessive fluoride in their groundwater). Over the past three years, he has been immobile; after which he was also diagnosed with mental health issues. She is the sole earner for her family. Despite qualifying for a Below Poverty Line card, which should ensure certain provisions such as food rations, MGNREGA work, seed and fertilizer subsidies, they have not yet received her card. She comes from a Muslim family, where women follow the *purdah* system. She is therefore not comfortable speaking with men or showing her face in the presence of men. She has tried to ask for help from the village panchayat and no one helps her out. She has slowly been figuring things out herself, without any assistance. Her *zamindar* (land owner) left her with many bags of Urea and DAP, which she used consistently for the first three years. After losing 70% yield of castor to frost and a majority of the *kharif* crops due to the poor quality of land and saline groundwater, she decided this year to stop applying chemical fertilizers completely, with a hope that in the next year, she can gain better yields.

Picture 6.2: Women perform various tasks around the village, including heavy tasks such as road building works for MGNREGA works (left) and more traditional roles such as weeding (right)

Source: Author's own

This example illustrates the difficulties faced by women, especially those from Rajput and Muslim households in accessing help. Many of the issues are deeply rooted within their cultural norms, where they have been sheltered from men, and are therefore unable to seek assistance when required. Wisner et al. (2012) and Cannon (2002) in their studies on risk also echo this finding that gender differences can at times be more an issue of culture than one of unequal access. For instance, traditional gender roles in Jodhpur are largely conformed to by women of the upper caste, particularly *Rajput* women, and less so by women in lower castes e.g. *Meghvals*. In Cluster I, women interviewed were generally of the *Jat* and *Meghval* castes (lower castes). They regularly participate in MGNREGA, attend community meetings and despite not owning land, demonstrate complete knowledge and control over their land and livestock. The women interviewed from the *Jat* and *Meghval* castes also have strong relationships within the community. On the other hand, *Rajput* women, despite their high standing in Rajasthani society, are expected to conform to traditional gender roles and are not allowed to contribute to agriculture or to socialise with women from lower castes.

In the arid landscapes of Jodhpur, especially in Cluster I, degradation-led out-migration, is a key contributor to the 'feminisation' of agriculture (Vepa, 2005; World Bank, 2009). A majority of men are migrating to urban areas for up to eight months every year, leaving women in charge of their farms, households and resources. For instance, in the household interviews, despite none of the households being officially headed by a woman, 23 out of 84 respondents in Cluster I and 10 out of 79 respondents in Cluster II, were women. While women have always played varied and important roles in agriculture, increased migration of men has in effect placed a 'double burden' on women. In addition to traditional domestic and livestock duties, women are now taking more decisions and performing many of the big agricultural tasks. In a society where women have been culturally and historically marginalised, the obligation to perform and manage all livelihood aspects has in some instances put significant pressure and burden on women.

As discussed in the vignette above (I_JJ9), women face many social, economic and political barriers in accessing productive resources and opportunities within their villages. However, it was found that while initial hesitations in accessing extension services and technical assistance was reported, eventually women learn how to gain and maintain access (such as II_JJ9). Women in some households now choose their crops, sowing times, and harvesting times and are involved in processing and transporting the crops to local markets. Households with women in charge (not in terms of land ownership but contribution to agriculture) were seen to use less intensive farming techniques, using organic manure from livestock instead of fertilizers like Urea, making a deliberate effort to not perpetuate existing degradation patterns in the area. In addition, women relied heavily on their social networks within the villages; women were found to be more willing to seek help and assistance from other women. For instance, many of the women, especially in Cluster I, indicated that they often cook meals together and for each other, share livestock duties, travel together to gather fuelwood and other tree products. They also lend and borrow products such as milk and fodder amongst each other. In 'sharing the burden' with other women in similar situations, vulnerable women-only households have been able to overcome some of the risks posed by out-migration of men in the communities.

Echoing these findings, Bunce and Ford (2015) critique the tendency to simply regard all women as a vulnerable sub-population while measuring their vulnerability in terms of gender-disaggregated data. Throughout the fieldwork, the narrative that women are more vulnerable was constantly challenged. In the villages, there were many examples of empowered women, who while adhering to societal norms of early marriage, early motherhood, and *purdah* took equal responsibilities with agricultural and familial duties. There are women who are in charge of the local schools, women who head the *panchayat* and women who are part of *mahila sangathans* (women self-help groups) in the two clusters. It is important to note that many women do not necessarily perceive themselves as disempowered. Many of the women expressed their trust in the system and culture within which they live, sharing that there are different forms of empowerment not easily understood by '*people like you*', in a critique of traditional development indices of women's rights.

A key finding is that women from upper castes i.e. *Rajputs* (generally perceived to be less vulnerable) have lower capacities to adapt than women from lower castes such as *Meghvals* in

Rajasthan. This finding is in contrast to assumptions made by targeted developmental assistance in India where women of lower castes are assumed to be more vulnerable in the context of land management (Bosher et al., 2007; Thorat, 2007). It is also important to note that women are not lacking in adaptive capacity in the way that they are often represented in literature as backward or vulnerable. Instead, the relationship between vulnerability and gender is far more nuanced, and women were observed to be prepared and willing to take responsibility for agriculture and livelihoods.

Summarising access to resources

In summary, access to services, institutions, and resources is mostly determined through the prism of caste, power, gender, and politics. This is often concealed or overlooked in traditional vulnerability frameworks that seek to address 'participation' and 'social capital'. A qualitative analysis has shown the inability of larger-scale developmental programmes (e.g. PDS, MGNREGA) and policies (e.g. land tenancy and pastureland policies) to circumvent local power structures, caste politics, and gender roles. These institutional developments have also failed to create new forms of local and participatory government, and have instead contributed to the erosion of traditional social and religious conservation practices; as well as deterioration in the collective capacity to adapt. The rural areas of Jodhpur are now better connected with decent infrastructure in comparison with the isolated livelihoods of the past. Yet, they remain vulnerable. Development in these areas has made for inequitable communities, constraining their innate strong abilities for agricultural and livelihood diversification in light of their risks. This decline in respondents reliable and equitable access to local resources, provisions and services, decreases adaptive capacity and increases vulnerability. It is also one of the main causes for the accelerated pace of degradation of landscapes in the region.

6.4.5 Sustainability of adaptive capacity

In addition to understanding social, economic, and institutional capacities to support adaptation, there is a need to evaluate current adaptive capacities to identify whether these are sustainable, purely in terms of whether they are reducing the future capacity to adapt. There can in effect be capacities to adapt that while being cognisant of current vulnerabilities do not undermine future capacities.

When studying endogenous vulnerability, in assessing a community's capacity to adapt, it is important to consider whether current strategies meet two simple criteria (see Figure 6.10):

- Sustainable: Capacity to adapt will be considered to be sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base.

- Flexible: Capacity to adapt includes successfully changing agricultural practices and livelihood patterns in line with dynamic situations and environments

Figure 6.10: Are the current adaptive capacities flexible and sustainable?

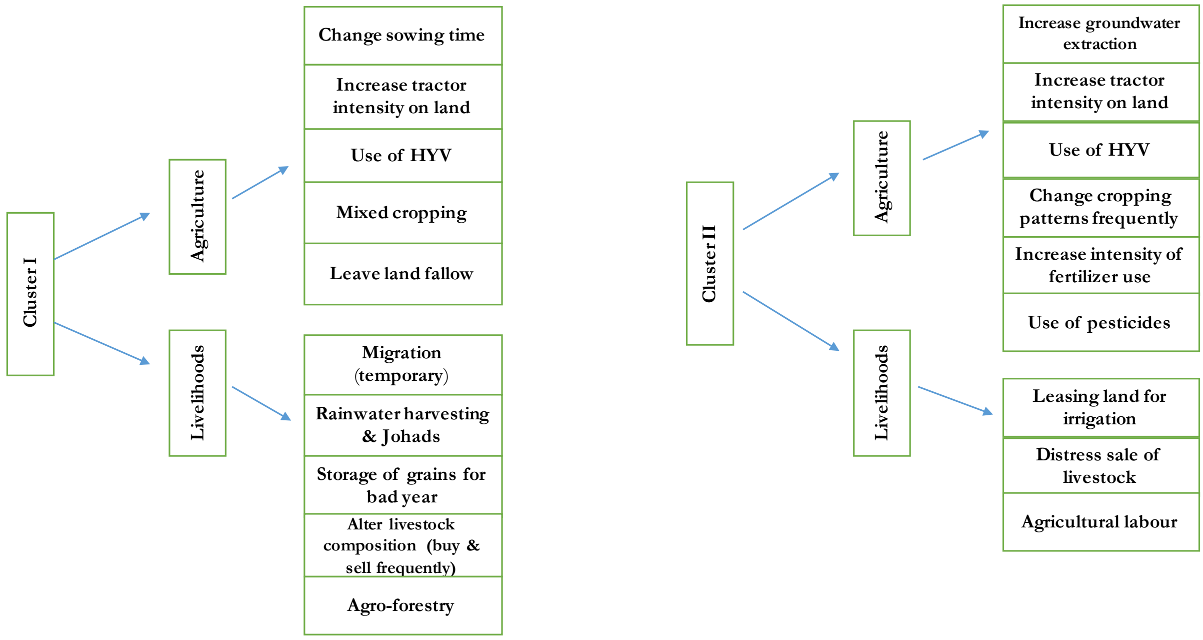
Flexible	Sustainable
Not flexible	Not Sustainable

Source: Author's own

A detailed history of the traditional management strategies used to cope with drought in Rajasthan is included in Chapter Three. While transformations driven by agrarian and social change have led to the discontinuation of many traditional adaptations, a few practices still remain. Furthermore, technological change and modernisation of agriculture has brought in newer forms of capacities to adapt. Figure 6.11 illustrates the main adaptive capacities currently in place in both Clusters. Unlike in other vulnerability assessments the capacities studied here are planned-reactionary practices[112]. Planned-reactionary practices refer to capacities that respondents put into use after predicting a certain impact, for instance, if a farmer feels the probability that rain will be delayed is high, they will shift to a short-duration crop or they will sow later. These are not ex-post reactionary, i.e. not incorporated after, but are in reaction to a particular predicted event.

[112] The forms of adaptive capacities have been distinguished according to numerous attributes such as purposefulness and timing (Bijlsma et al., 1996; O'Brien et al., 2004a; Reilly & Schimmelpfennig, 2000). Most vulnerability assessments include for either planned/anticipatory adaptation or coping/reactionary adaptation practices. In the field, it was found that most current adaptation practices are planned but are reactionary (not generally geared to the long-term)

Figure 6.11: Main current adaptive capacities in Cluster I and Cluster II



Cluster I

In Cluster I, the capacity to adapt is largely channelled by traditional knowledge and coping strategies. Many households continue to practice sustainable land management strategies such as the use of organic manure from their own livestock. To a lesser extent, they continue to practice alternate/rotational/shifting cropping patterns. Fallow periods between cropping seasons have decreased from around three-year fallows to one-year fallows.

Cropping patterns in the cluster have remained the same for centuries with respondents showing little flexibility in trying different crops. Respondent I_Kh5 stated:

"There is a reason we grow bajra here and they grow wheat in Punjab, and rice in Karnataka. It's because this is what our land can best produce keeping in mind its strengths and limitations; bajra and moth bean also provide the nutrients our bodies need to keep us healthy in our climate".

This quote expresses a strong argument of both the suitability and adequacy of traditional crops to both nature and human well-being.

Most households in this cluster also diversify their livelihoods to include non-agricultural activities, such as rearing livestock, selling ghee (clarified butter) made from milk to neighbours and collecting agro-forestry products. Tree products are put to interesting use; for instance, *bajra* is traditionally used to make flour for bread which is a staple food in the area. During seasons where *bajra* yield is insufficient, they mix water with seeds from the *khejri* tree to make dough. Similarly, a majority of their food comes from dairy preparations and products from the trees that grow on their farms. All farmers grow cucumber (*Kachra*) and watermelon (*mathira*), which is used in making a semi-dry curry (eaten in accompaniment with their *Bajra roti*). Before vegetables from neighbouring states started becoming popular, watermelon was their primary 'vegetable', made popular due to its ability to cool down the body in the hot desert summer. The seeds from the watermelon are replanted for the next year, or if in excess are sold in nearby villages. A majority of farmers showed little interest in installing irrigation systems on their farms, calling it 'unsustainable' and 'bad karma' in the long-run due to the poor quality and availability of groundwater around their villages. In some villages promotion of fruit species such as Pomegranate, Lemon, Sapodilla, Sweet Lime, Custard Apple and Mango are being tested, with support from local institutions such as CAZRI, so as to develop alternative support for their agriculture for the future. They continue to rely on rainwater harvesting for six months of the year, and continue to construct and use traditional storage systems (*kothas*) to store grains for bad years.

Tractor intensification is now greater and the farmers increasingly prefer to use hybrid seeds (due to their quicker development times) although not all were equally satisfied with the quality of grains. They remain generally flexible with their sowing times, waiting for clouds and other signs of rain before sowing. Respondents reported *kharif* sowing as early as May and as late as August. Many stated however that delayed sowing leads to a reduction in crop yields.

The use of distress coping strategies is common during extreme drought or crop failure, and includes strategies such as food rationing, migration, and selling off livestock and assets. These strategies have been in place for many generations, and the only significant change in recent times has been longer-term migration of men to far away cities. Previously, men migrated with livestock or to nearby villages and towns, looking for daily wage labour. The development of roads, unpredictability of climate, and growing wealth around them has driven many men in the villages of Cluster I to seek long-term prospects outside the village. Most men work as truck drivers across India, and are away for 8-9 months a year, leaving their women in charge of the households. Respondents universally revealed a strong willingness to remain in their villages. Migration for them is largely driven by livelihood risks in their villages, more than the 'pull' factors associated with a particular destination; they are especially mindful of the large differences of lifestyle between the city and their villages. A study on coping strategies in two semi-arid villages in Karnataka shows similar results, where migration is largely an unwelcome strategy for farmers, who prefer to stay in the villages, working on their fields (Kattumuri et al., 2017).

Overall, the respondents in Cluster I were not entirely flexible in their cropping patterns, due to:

- Their more rigid beliefs in their understanding of the capabilities and limits of their land;
- Their risk-averse nature; and
- The general lack of focus on cash-based income

However, whilst incorporating newer means of cultivation such as the use of hybrid seeds, tillage equipment and growing interest in agro-forestry based farming systems, a majority of respondents continue to rely on traditional agricultural systems and resilient livelihood practices.

Cluster II

In Cluster II, the capacity to adapt is largely channelled by transformations triggered by the Green Revolution. While some respondents continue to use organic manure from their own livestock; a majority of their agriculture is now entirely reliant on the use of synthetic fertilizers supported by groundwater irrigation. Even farmers with no sources of groundwater on their land were seen to lease irrigated land from larger farmers or buy tubewell water from their neighbouring farms. Few farmers practice mixed cropping, alternate/rotational/shifting cropping patterns; and land under current fallow was almost non-existent. Key crops grown in *kharif* are *bajra* (typically with irrigation water); and crops grown during *rabi* include, cotton, castor, wheat, carrots, cauliflower among others.

Farmers here are more flexible with trying newer cropping patterns. For instance, many stated that due to pests and frost-related crop losses in castor and cotton, they have made the recent shift to carrot, which is less impacted by weather changes. A similar change in cropping pattern was reported 10 years ago, where chillies, cumin, wheat and isabgol were the key cash crops in the region but soon productivity of these crops started dwindling. While irrigation and associated inputs (such as fertilizers and pesticides) have provided benefits thus far, deficiencies in groundwater are leading to problems of intensifying degradation and lowering crop yields. Traditional livelihood adaptations such as rainwater harvesting and storage of grains for bad years have been almost entirely discontinued in Cluster II.

The use of distress coping mechanisms has increased in the Cluster, indicating that existing capacities to manage risks are being tested. They include, irrigating only a portion of their land, shifting back to rain-fed farming, selling off livestock and smaller parcels of their land. Barring a few households (such as those in the village of II_RB, where Muslim pastoralists own large numbers of sheep and goats); a majority of households only own cows and buffaloes. Due to greater land under irrigation, demand for agriculture labour is also high, which means there are fewer members migrating when compared with Cluster I. In Cluster II only 9% of HH members migrate seasonally. This means a majority of both land owners and landless labourers rely on agriculture as a primary source of livelihood.

Overall, households in Cluster II are flexible in their sowing patterns i.e. if a crop does not suit the climate or land, and they are not averse to changing it. Their focus is on cash-based income, even if it is short-term. Further, the respondents while aware of the impacts of current actions on their land, are mostly headed towards a transition to maladaptation, through intensive cultivation and excessive reliance on groundwater as a source of income. Their trajectory is clearly not one of sustainable agriculture or livelihoods.

In determining the viability of current adaptive capacities of both clusters with respect maintaining critical levels of natural capital (Ekins et al., 2003) i.e. sustainability, it is clear that traditional practices are more sustainable, while also offering some flexibility in crop selection and timing of sowing.

6.5 Conclusions

The chapter offers theoretical, methodological and empirical contributions to existing drylands research.

Using the framework of endogenous vulnerability as a function of sensitivity and lack of adaptive capacity, an agriculture and livelihood vulnerability index (AgLiVI) was developed. This chapter explored the analytical utility of a vulnerability index (AgLiVI), developed using criteria and indicators. In doing so, the analysis makes three significant contributions to our understanding of vulnerability indicators for dryland agro-ecosystems: (i) developing a human-centric endogenous vulnerability approach, where drivers of vulnerability are embedded within a socio-ecological system; (ii) using community-identified, context-specific indicators that are relevant to the unique dryland study locations, focussing in particular on 'quality' of measurements; and (iii) assessing vulnerability across multiple scales: households, villages and clusters.

Finding 1: Findings from the AgLiVI showed that Cluster I has a AgLiVI value of 0.58 and Cluster II a AgLiVI value of 0.63, both indicating high vulnerability for the region. At first glance, differences between the AgLiVI scores between the two clusters seem minimal. However, upon closer inspection, analysis reveals a number of subtle yet important differences between the two. The results show that sensitivity in Cluster I is a combination of land degradation, poor crop productivity, and complicated social dynamics. Lack of adaptive capacity was driven by poor access to agricultural inputs (e.g. irrigation). In Cluster II, sensitivity was largely driven by degraded land and groundwater resources. With regard to adaptive capacity, communities were most affected by their lack of both crop and livelihood diversification (relying largely on cropping for income), with minimal reliance on traditional livelihood capacities. These context-specific findings can add value to decision makers who often prescribe similar solutions to communities that are geographically located this close to each other. Furthermore, the relevance of the index to the two differing clusters demonstrates the potential utilitarian value in transferring the use of this mixed methods approach to other drylands.

Finding 2: One of the key findings of the analysis is that despite their limitations, vulnerability indices can provide valuable insights. Using both objective and subjective context-specific indicators can provide results that are testable, useable, and representative of the vulnerabilities experienced by communities at a given time. Criticisms of vulnerability indicators, often rooted in an index's narrow framing and limited renditions of ground-level truths, can therefore be overcome. The problem rather lies in the depth of the information derived, which means as with any assessment of indicators there is a need to remain cautious about applying the approach and interpreting the results. The most significant of these dynamics is the intersecting nature of socio-ecological interactions, which are difficult to capture in an index, simply because the interactions are difficult to quantify. There is also no data available to model and translate these interactions into useable findings. These interactions are critical and by being cognisant of the hybrid nature of their occurrence, we can perhaps be more attentive to endogenous vulnerability and its impacts on land use and land degradation. Being mindful of the complex nature of vulnerability, a qualitative analysis was then used to enhance and complement the quantitative analysis.

The index provided an initial framework within which to understand vulnerability, highlighting who is vulnerable, and why are they vulnerable. A qualitative, narrative-driven approach, was then used provide further insights into the dryland agro-ecosystems of Jodhpur. In re-examining responses from the field study, three concepts were developed for analysing vulnerability keeping in mind the fragile nature of dryland agro-ecosystems. The new conceptual framework proposed a more in-depth study of vulnerability focussed on three concepts.

(1) *Sensitivity thresholds of land, water, biomass resources and societies:* Taking stock of the fragility of land and related resources and societies, using local knowledge;
(2) *Lack of 'reliable' or 'true' access to resources and support institutions:* Focussing less on the presence of assets and income, and more on resources, institutions and livelihoods; and
(3) *Sustainability of adaptive capacities:* Ability of their existing adaptive capacities capabilities to sufficiently mediate current risks without impacting future resilience.

As indicated in Chapter Two, while drylands challenges differ based on political and social context, the above three principles will likely prove valuable across drylands in the Global South. An ideal vulnerability assessment for drylands can incorporate these three important elements and tailor the constituent and crosscutting vulnerability elements according to the socio-ecological context. The mixed methods approach used in this analysis thus enhances the results of the index through adequate substantiation at a ground-level.

Finding 3: Analysis from both the index and enhanced qualitative vulnerability framework show that Cluster II, despite access to technological transformations and innovations, is more vulnerable than the more arid and remote Cluster I. Through this analysis it was found that in Cluster I, communities while aware of transformational changes brought on by market-driven growth, are yet to fully invest their future in them. A lot of control in Cluster I belongs to local power clusters (i.e. panchayat leaders and their allies), and those in the dominant or upper caste. Due to their apprehension in intensifying land beyond certain thresholds, and their reliance on rain-fed cropping, their current individual capacity to adapt is weak. However, their joint capacities are high, as community cohesion and inter-intra household relationships are drawn upon during times of distress. Furthermore, although deteriorating, their reliance on traditional coping capacities remains strong due to the reliance on traditional practices such as mixed cropping, traditional millet cultivation, and maintenance of diverse livestock composition among others.

In Cluster II, communities maintain their innate ability to recognise and identify threats to their resources and social customs. However, the lock-in precipitated by transformational changes has eroded traditional resilient capabilities that disadvantage them from responding to their concerns. The presence of irrigation on most farms means their individual capacities to adapt are strong in the present time. Both community cohesion and inter-intra household relationships are less relevant in Cluster II. They have been replaced by newer and more formal arrangements such as land leasing and tractor renting that have their benefits but in the current form are dominated by manipulative *ex-zamindars*.

Finding 4: Vulnerability in arid drylands is atypical and unique in comparison to vulnerability in semi-arid, humid regions: In reviewing results from other vulnerability analysis conducted in India, most studies conclude that market access and irrigation are key vulnerability reducing mechanisms, and communities with access to the two will be less vulnerable. In this study, analysis from both the AgLiVI and the narrative-driven vulnerability analysis show that Cluster II is more vulnerable than Cluster I, due to land degradation, excessive reliance on dwindling and poor-quality groundwater reserves, and the resulting lack of livelihood diversification. Most significantly, households in Cluster II appear to be on a trajectory of 'maladaptation' leading to deepening unsustainable modes of resource consumption. This shows that in arid regions, irrigation and access to markets, while providing benefits to both agriculture and livelihoods, are not in themselves enough to reduce vulnerability, even in the present time.

As discussed earlier in this thesis, developing actionable vulnerability frameworks that are relevant to drylands communities in the field has been challenging. Keeping in mind findings from the AgLiVI and the rich contextual information from the field study, this research is well positioned to fill in some of the key gaps of the indicator-only vulnerability assessments. The proposed approach moves away from simpler generalisable taxonomies of vulnerability, such as 'women are vulnerable'; to an approach that instead considers vulnerable situations.

Through the analysis conducted in this chapter, the research identified:

- Who is vulnerable?
- Why are they vulnerable?

It is now important to close the loop[113] on vulnerability and study how vulnerable households and communities in turn are responding to their vulnerability. This will help to place the vulnerability analysis in the context of the key environmental (dryland degradation) and developmental challenges faced by the communities in question; and their abilities to manage these risks. The next chapter explores some of the responses of households located at different stages of vulnerability. The analysis will identify the central role played by vulnerability, both as a cause and consequence of dryland degradation.

[113] Term is taken from Fraser et al. (2011), although used by authors in closing the loop in the context of closing the loop between local knowledge and scientific information.

7. Closing the Loop on Vulnerability and Land Degradation: Designing Assessments for Effective Adaptation

There is a strong consensus emerging from the international community that the collective inability to address land degradation has been due to a failure to convince decision makers of the urgency of the risks posed by it (Akhtar-Schuster et al., 2011; UNCCD, 2016). In India, progress has been made in recognising the threat of dryland degradation. The government regularly monitors the extent of degradation and policies that promote sustainable land management have been introduced (e.g. drip irrigation, watershed management). However, neither decision makers nor researchers have acknowledged the socio-political drivers of change, some of which are rooted in the vulnerability of local dryland communities. This chapter will address this important gap and answers research question three: **'How can vulnerability be incorporated into broader land management and adaptation planning, so as to sustain dryland agro-ecosystems through reclaiming land resources while enhancing resilience to the effects of climate variability and change?'**

Evidence from Chapters Three and Five shows that the district of Jodhpur has always been exposed to climatic hazards but climate variability is now intensifying, pushing landscapes and communities beyond their existing adaptive capacities. In Jodhpur, land is tied in closely with cultural identity, and land availability, quality, and productivity are central to rural socio-economic systems. Thus, the mounting risks posed by dryland degradation can have impacts beyond what is currently appreciated. Using vulnerability as an integrating concept, analysis in this chapter will demonstrate to decision makers why some groups are successful in managing their land in a relatively resilient way while others are not.

This chapter distils key principles for designing effective adaptation policies and programmes to climate variability and change, based on evidence from the previous chapters, as well as from past developmental policies and programmes in India. Using examples, 'vignettes of the vulnerable', it demonstrates that understanding vulnerability is a critical first step to the design of adaptation and sustainable land management strategies. The chapter emphasises that vulnerability to multiple stressors, is not just an outcome of dryland degradation (as is typically suggested), but that vulnerability in itself can be an important driver of dryland degradation. The chapter concludes by providing a broad approach and strategy to address vulnerability and dryland degradation jointly.

The chapter is organised as follows:

- Section 7.1 links findings from the previous three chapters on climate hazards, exposures, and vulnerabilities using a risk framework;

- Section 7.2 highlights current approaches to managing risks in Jodhpur's drylands, focusing in particular on the government's fixation with transforming existing systems and its propensity to increase vulnerability through possible maladaptations;
- Section 7.3 highlights the role of vulnerability in managing risk through introducing four new vulnerability typologies, and drawing attention to them using case studies that demonstrate the diversity of farming in the region;
- Section 7.4 draws out the links between these different vulnerability typologies, land use, and dryland degradation; and
- Section 7.5 summarises by providing a way forward for research and planning for sustainable land management and adaptation to climate risks.

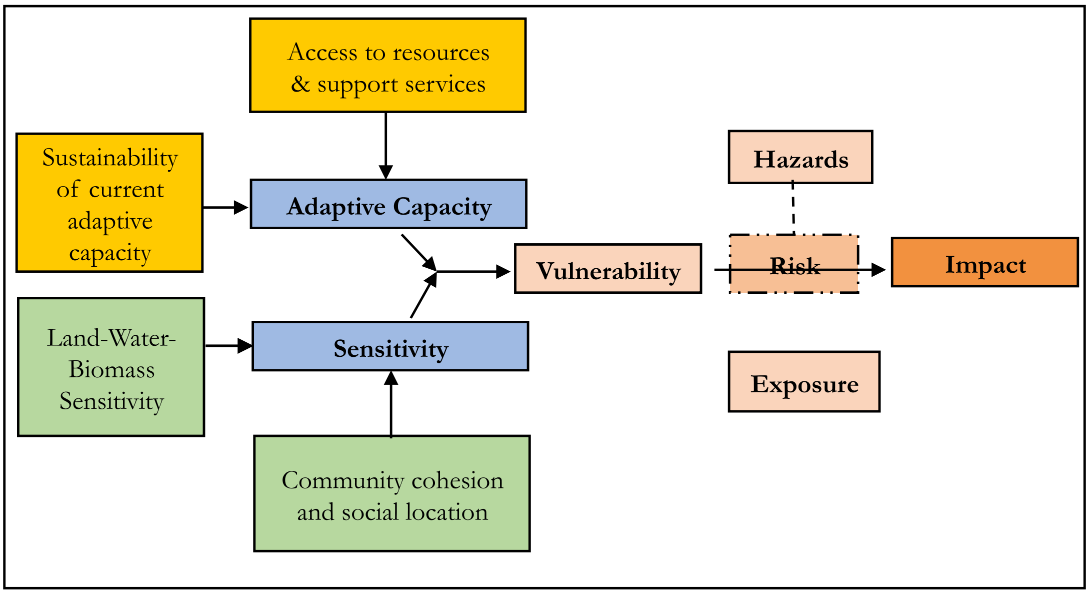
7.1 Background: Managing risks in dryland agro-ecosystems

The IPCC (2014) framework of risk presented in Chapter Two shows that risks are triggered when a vulnerable socio-ecological system is exposed to a climatic hazard. Climate hazards, exposure, and vulnerability are in turn influenced by a wide range of factors including, anthropogenic climate change, natural climate variability, socioeconomic and political development (IPCC, 2014). While risks are unlikely to be fully eliminated, managing risks to reduce adverse impacts is a priority. In managing risks, such as those related to dryland degradation, and adapting to climate change, the focus needs to be on improving resilience (Hesse et al., 2013), while reducing exposure and vulnerability.

Figure 7.1 illustrates the core concepts to be dealt with in managing risk. It is adapted for this study from the IPCC risk framework of AR5 (see Figure 2.4). It helps put in context the concepts evaluated thus far in the study:

- Hazards and exposure: In Chapter Five, an analysis of meteorological information and community perspectives showed the extent of hazards posed by increased climate variability in the two clusters selected for study. Evidence from both primary and secondary data indicated that the land in large parts of Jodhpur district is already degraded and newer lands are at risk of degradation. The combined effects of dryland degradation and climate variability have therefore led to heightened exposure in the study region.
- Vulnerability: Results from both the AgLiVI and the qualitative vulnerability analysis in Chapter Six, showed both clusters to be vulnerable due to their prevailing socio-ecological attributes. Cluster II (irrigated) is found to be more vulnerable than Cluster I due to greater sensitivity of its land resources, the erosion of social networks, and a lack of livelihood diversification.

Figure 7.1: Land degradation risk, vulnerability, and drylands. In areas with high exposure, hazardous climatic events interact with vulnerable socio-ecological systems, increasing the susceptibility to disaster risk



Source: Author's own (adapted from the IPCC risk framework)

As shown in Chapter Three, western Rajasthan, where Jodhpur is located has long been exposed to climate hazards (droughts, rainfall variability, high summer temperatures, and wind velocities are common) due to location, geomorphology, and large human and livestock populations that are directly dependent on the land. An analysis of meteorological data showed that climate variability is increasing with unstable monsoons, unseasonal rainfall (such as in September), and hotter summer months. In addition, communities observed unfamiliar and unpredictable climatic hazards including: scattered rainfall, winter frost, and increasing wind gusts in the months of September and October. In the meantime, the population continues to rise, with the region already the most densely populated arid zone in the world (it has a population density of around 165 people/sq.km). Results from Chapter Five showed that the association between climate variability, land use, and dryland degradation is complex and intertwined, putting the region at the crossroads of potential disaster risk[114]. Disaster risk implies that a community functioning normally will experience widespread adverse impacts and disruptions on their food security, economic stability, socio-cultural legacies, human, and environmental health.

[114] Disaster risk is defined as the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC, 2014).

To manage such risks, strategies are needed that reduce vulnerability and promote adaptation (Mimura et al., 2014). The central government in 2015 established a pilot National Adaptation Fund on Climate Change (NAFCC); "the projects to be funded out of NAFCC will aim at implementation of adaptation measures/interventions in the given sector/sub-sector exclusively designed to reduce vulnerability" (MoEFCC, 2016: 2). At the state level (in Rajasthan) there are currently no dedicated adaptation programmes in place. There are however many developmental programmes that seek to provide adaptation benefits through managing climate risks and enhancing resilience. Many have been discussed throughout this thesis. e.g. MGNREGA, Public Distribution Systems (PDS), watershed programmes, among others. As discussed in Chapter Six, they face implementation issues at the local level. Thus, there remains an urgent need to develop specific adaptation strategies, such that the point of disaster risk is not reached.

As discussed earlier in this thesis, a key constraint in drylands has been the inadequacy of present frameworks to characterise and understand vulnerability (Costa et al., 2011; Fraser et al., 2011; Low, 2013; Reed & Stringer, 2015; Young et al., 2010). This has led to risk management strategies that are largely reactive responses to just the 'climate hazards', without adequate attention being paid to the key socio-political and ecological context within which they occur. Many current strategies to managing risks in Jodhpur's arid drylands have looked towards transforming existing societies to help them cope with risk, wrongly misinterpreting that their traditional livelihoods are ill-equipped to manage critical land resources and ensure food security. These very transformations over time are leading to possible maladaptations that exacerbate dryland degradation and intensify vulnerability. Further, adequate attention is not given to the resilience present within traditional knowledge systems. In response to past climate hazards, the transformations led by past and current approaches to risk management in Jodhpur have been discussed throughout this thesis. The following section puts a focus on the most significant transformations.

7.2 Transforming Jodhpur's drylands: Current approaches to managing risk

'Transformations' here are defined as changes that alter the fundamental attributes of a system including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems' (IPCC, 2014). Current responses to managing risk in Jodhpur are largely outcome-oriented reactions to: (i) growing climatic concerns, specifically droughts; and (ii) persistent developmental problems relating to poverty and food insecurity. Responses highlighted in this section relate to the changes made within local communities that have been triggered by external factors including government policy and markets.

7.2.1 Land use transformations

The 'land under fallow' in both clusters has been replaced by 'net sown area'. This particular shift in land use change is emphasised, since a persistent increase in 'net sown area' is a good indicator of land intensification (Reddy, 2003). The increase in net sown area is largely in response to shifts in agriculture initiated by the 'grow more food' campaignof the 1950s and followed up by the Green Revolution in the late 1960s, which introduced new technologies and market-driven growth. Increased demand for food and greater support for irrigation through canal, tubewell and rural electrification led to an increase in the use of agricultural machinery. The growing uncertainty of their surrounding climate has also made farmers more reliant on new technologies and farming practices.

In Cluster I, although a few farmers still practice fallowing, scarcity of good quality land and lack of availability of organic manure has led to many abandoning this practice. In Cluster II, shifts have largely been in response to increasing pressure from market-driven growth to produce more and increase cash income. For example, in Cluster II, changes in cropping patterns can be observed from hardy weather tolerant millets and pulses to cash crops such as vegetables, that are less able to tolerate the variable climate of the region. As large and medium landholders abandon traditional agricultural practices (e.g. fallowing) and intensify their land for greater productivity, smaller farmers often feel compelled to follow a similar path. The intensification of both smaller and larger landholdings has contributed to exacerbation of degradation in recent years.

7.2.2 Social transformations

Both clusters have experienced significant changes in the way societies organise themselves with respect to their land. Firstly, the shift has been from a more balanced use of resources (where only the agricultural castes put pressure on their land) to one where all sections of society are reliant primarily on agriculture. Social systems traditionally developed around the idea of maintaining equilibrium between natural resources, have now evolved into inequitable systems. In Chapter Five (Section 5.6.3) the significance of loss of pasturelands and responses of nomadic *Rabari* communities were explored. Many such examples of changing social livelihoods were shared by respondents. Some of these transformations have been led by opportunities now present in agriculture while others have been driven by the lack suitable alternatives. This has led to the increased dependence of livelihoods on agriculture, and subsequent pressure on the land. This enhances the vulnerability of rural communities to climatic hazards, due to a lack of livelihood diversification.

Secondly, there has been a noticeable shift from the traditional Indian joint family (where risk was shared by all within a large household) to nuclear families. This is discussed in detail in Chapter Six, where families initially split to evade land reform policies (particularly the Land Ceiling Act). This has eventually led to smaller parcels of land being intensified and degraded. Importantly, it has also eroded familial bonds and intra-household relationships, increasing vulnerability to climatic risks. Land reforms have also had a limited impact on changing land holding patterns; ex-*zamindars* continue to own a majority of land, particularly in Cluster II.

Thirdly, there has been visible erosion of inter-household relationships, evident in the way communities now interact with each other. As discussed earlier, *dhanis*, which are dispersed homesteads, are situated away from the centre of the village. Due to their dispersed nature, communities in *dhanis* and between *dhanis* have to be fairly self-reliant in maintaining food security. The rural areas of Rajasthan are vast and remote, and adequate infrastructure, albeit improving, is yet to reach many remote *dhanis*. All network infrastructure and institutions (e.g. piped water) are supplied to the village centre, incentivising most to split up their families and move to smaller houses in the village centre. Traditional informal risk strategies are replaced with more formal arrangements, which currently are mostly governed by vested interests of local power.

7.2.3 Declining traditional resilience

Water scarcity has for centuries been the main concern in the region. Resilient agricultural and livelihood strategies have sustained both human and livestock populations in the region. Many resilience capacities have been highlighted in Chapter Three such as *tobas* (rainwater harvesting structures), *khadins*, *kothas*, fallowing, nomadic livestock management, and shifting cultivations. In Cluster I, some of these practices continue, although they are becoming less important. In Cluster II, these practices have diminished due to the increased role played by technology, in particular irrigation. While newer developments such as HYV seeds have the potential to be beneficial (Pretty et al., 2011), in this study it was found that suitability to the arid agro-ecologies has not been adequately tested.

Respondents in both clusters indicated that the use of natural catchments such as *tobas* and *baoris* are currently not in use, and run perennially dry. In Cluster I, household rainwater harvesting tanks continue to be a main source of drinking water, with close to 80% of households interviewed using the harvested rainwater for around 4-6 months every year. Furthermore, a number of *johads* (village water tanks) still exist in the village centres of Cluster I for livestock to use, especially during the winter (Picture 3.2). In Cluster II, on the other hand, only 15% of households interviewed used rainwater harvesting structures. As respondent II_RB3 explained:

"We have so many tubewells in our village, that we stopped needing our rainwater harvesting tankas 20 years ago. The problem we have now is that the groundwater is too saline to drink. Even my cows don't drink the groundwater due to how salty the water is; we are left with no rainwater tankas and we have to buy water through tractor tanks of water every month".

This quote indicates that access to tubewell water, while addressing issues of water scarcity, has led to a loss of their traditional water harvesting capacities which were in use for centuries. Over the past five years, groundwater quality and quantity has declined and now risks putting communities back into situations of severe water scarcity.

Furthermore, in Cluster I, 60% of the households interviewed still use *kothas* or other traditional methods of food grain storage, while none of the households in Cluster II use them. Farmers with *kothas* reported that during drought years, they rely entirely on stored grain for food and fodder. This reduces pressure on the land to provide food security during drought years.

Thus, most traditional crop and water management practices, which evolved over centuries of exposure to hazards have been abandoned, reducing the innate resilience of communities and increasing vulnerability.

7.2.4 Agricultural and social transformations: Possible maladaptations?

Planning for adaptation encompasses an enormous range of activities and processes, and will vary greatly from context to context. Adaptation here has been broken down into three broad categories, keeping in mind past research (Brooks et al., 2005; Brooks et al., 2011; Hesse et al., 2013; IPCC, 2014) and results from the field study:

Transformational versus incremental adaptation: As discussed earlier, transformational adaptation looks to change fundamental attributes of a socio-ecological system in response to climate hazards and their impacts. Incremental adaptations seek to maintain the integrity and essence of a system when not all aspects of developmental and social life are in need of transformation. Current adaptation in arid drylands of India is more inclined towards transformations of existing socio-ecological systems.

Outcome versus inherent approaches to vulnerability: Reducing vulnerability is the first step in adaptation planning (IPCC, 2014). In Jodhpur, it is clear that current responses to managing risks are largely reactionary and have been geared towards modifying exposures (e.g. rain-fed agriculture to irrigated agriculture) to climatic hazards through:

- Eliminating local reliance on rainfall through investments made in irrigation technologies by farmers supported by local governments; and

- Changing social ideals in line with newer forms of engagement such as land leasing between communities and households.

There is little focus on: (i) the pre-existing state of the system or socio-ecological context within which the particular adaptation is being planned (e.g. excessive focus on groundwater irrigation in an area where groundwater has turned saline); (ii) emergence of newer and unfamiliar climatic patterns that can make current adaptations inadequate (e.g. wind gusts interacting with unseasonal rainfall and their impacts on adaptive HYV crops as discussed in Chapter Five).

Utilitarian versus egalitarian approaches: Brooks et al. (2011) define utilitarian approaches as those where interventions seek to benefit the largest possible number of people, to ensure maximum efficiency. However smaller populations and regions that may be atypical in terms of climate or other hazards are often neglected. This is evident in agricultural and developmental programmes in India that ignore the arid drylands (e.g. policies that are targeted on sub-humid and fertile areas). Egalitarian approaches are those that focus largely on the 'vulnerable' sections of the population. This is another approach particularly popular among developmental assistance in India, whereby the poorest are often equated with the most vulnerable.

In both clusters, agricultural and social transformations have been driven by larger-scale developmental programmes, governmental policies and market-led growth. These have contributed to the way communities in Jodhpur use their land. Erosion of traditional practices has directly contributed to increased pressure on land resources, contributing to intensification of degradation risks. The absence of information on the impacts of these transformations illustrates that the approach taken towards measuring the risks of dryland degradation has been inadequate. It has only intensified vulnerability and undermined resilience, indicative of trajectories of maladaptation, where inadvertent or badly planned adaptation actions can increase vulnerability (Adger et al., 2003).

There is thus a need to correctly identify and characterise vulnerable communities and land use systems so as to avoid maladaptation. The development of vulnerability profiles has been put forth as an important ongoing agenda by India's MoEFCC, where the profiles are used to greenlight projects under India's new NAFCC, established in 2015. Thus, it is essential that vulnerability profiles and assessments are developed whereby targeted assistance is relevant and adequate to the communities and sections of society they are meant for. The next section will provide a systematic method to analyse how people use the land and its interactions with their vulnerability.

7.3 Vulnerability Typologies

A central theme in this thesis has been the role of vulnerability in dryland degradation. it has proven difficult to account for the complicated and unique nature of drylands, while keeping in mind the broader conceptual boundaries drawn up by vulnerability research. In Chapter Six, an index-based vulnerability analysis was developed, followed by a more qualitative, narrative-driven vulnerability assessment. In keeping with the conceptual framework in Chapter Four, it is expected that knowledge of this socio-ecological vulnerability will provide a better understanding of the factors increasing the risks of dryland degradation in the region.

Taking forward the knowledge gained from the vulnerability analysis in Chapter Six, four new vulnerability typologies are proposed, along a continuum. The four typologies allow for the examination of an individual household's strategic behaviour, embedded in historic repertoire, in social differentiation and perceptions of risk (de Haan & Zoomers, 2005). Within each typology, links between vulnerability, land use strategies, and outcomes on land are established. Figure 7.2 illustrates where different typologies are located along the continuum of vulnerability.

Figure 7.2: Vulnerability typologies along a continuum for dryland agro-ecosystems

1. **Low vulnerability:** Low to moderate apparent degradation of land, water, and biomass resources. Individual and community capacities to cope are strong, and households are well located socially[115]. Households use both traditional and modern capacities sustainably to adapt to current climate variability, so as to derive maximum benefit now, without degrading resources. Households belonging to the dominant caste or upper caste Hindus, with medium to large landholdings in both clusters fall into these categories. High education and skill levels are also key characteristics of this category. Due to the diversity of their livelihoods and cropping systems, adaptive capacities of these households are high.
2. **Vulnerable yet resilient:** Moderate to high apparent degradation of land, water and biomass resources. Sensitivity thresholds of their resources remain threatened. Traditional capacities for maintaining resilience remain strong despite growing social, economic, and environmental transformations around them. While maintaining traditional capacities, they also adopt newer technologies, such as HYV seeds, and

[115] Social location refers to a combination of caste and local power structures and where individuals lie in comparison to others.

tillage within limits (so as to not negatively impact on the land). Additionally, while individual capacity to respond varies according to their social location, their collective capacity[116] has remained strong. A majority of households in Cluster I fall into this category.

3. **At the tipping point of vulnerability**: Moderate to high apparent degradation of land, water, and biomass resources. Sensitivity thresholds of resources remain threatened. Both social and ecological transformations have led to systemic changes that households are currently unsure of how to respond to. Many respondents in this category have noticed their land quality degrade and they are exploring new avenues to manage the new system state. This includes households that have had to shift in recent years from being semi-pastoralists to primary cultivators, households that have recently started to use chemical fertilizers, and households where land fragmentations have forced farmers to rely on institutional support and irrigation technologies. Their traditional knowledge and capacities to identify hazards remain intact, but they are not putting them to practical use. Their individual capacities to respond to climate risks have remained intact but they have lost out on collective capacities to respond. While some of these respondents may not appear to be vulnerable in a snapshot in time, they are not resilient either. Their lack of resilience lies in the very transformations that have led them to eroding their traditional capacities to adapt. A majority of respondents in Cluster II and some respondents in Cluster I are in this category.
4. **Vulnerable**: Land, water, and biomass systems are degraded, negatively impacting on cropping patterns and yields. Their individual and community capacity to adapt are both eroded. Their traditional capacities to recognise and cope with hazards are diminished, and all current adaptation practices are proving unsustainable, even in the near-term. Vulnerability has increased in all three key dimensions of their livelihoods: the land they till is degraded; groundwater has declined and quality degraded; and they have lost both their individual and collective capacity to adapt. Most respondents in Cluster II belong to this category due to their excessive reliance on poor quality groundwater and tractor implements; and a few landless labourers in Cluster I are in this category.

Each of these typologies are explored in the following sections using four vignettes of farming, taken from the detailed life histories[117]. For each vignette, the following two intentions are set: (i) to envision pathways of people moving between the different vulnerability categorisations

[116] Collective capacity refers to community level cohesion (e.g. intra-household relationships and participation in village level activities) that improves an individual household's capacity to adapt.
[117] see Chapter Four for details on methods followed in collecting life histories.

and; (ii) to identify how households in different vulnerability typologies differ in their resource-use behaviours.

In the AgLiVI (Section 6.2.5), vulnerability ranks between 1-5 were given to the households. The significance of vulnerability ranks in targeting adaptation planning and broader developmental assistance was discussed there. However, its use in research has been limited. Authors such as Sharma (2015) argue that this is because a vulnerability rank does not add standalone value to the results. In the following sections, these arguments are explored by comparing the AgLiVI ranks with the in-depth vignettes presented for each typology. These comparisons are important since, as discussed earlier, a ranking of vulnerability is likely to be the one of the most important practical outputs appropriated from a vulnerability analysis by decision makers, looking to target assistance.

7.3.1 Low vulnerability

Cluster: I**: Village:** Khari Beri **Respondent**: I_ KB16 (Ram Singh)[118]
AgLiVI rank: 3 (moderate)

Ram Singh is the head of a five member *Rajput* household. He now lives in the village with his wife. His family have lived in this village for centuries. This *Rajput* pioneer village[119] is now dominated and run by *Kumhars*. He owns 5 ha of cropland on which he regularly practices traditional mixed and rotational cropping, where he apportions 3 ha for cropping and 2 ha fallow (on a rotational basis). Crops grown are pearl millet (*bajra)*, pulses (*mung*, *moth*), sesame (*til)*, cluster bean and watermelon (*mathira).* In addition, his wife regularly grows chillies, garlic and aubergine in small portions of their land for home consumption, using water from their rooftop rainwater harvesting tank. None of their yields are sold in the market and excess *bajra* is stored away for fodder. On his land, he has four types of agro-forestry tree species including *khejri* (80 trees), *rohida* (25), *neem* (10) and *desi babul* (10).

Ram owns one cow, three buffaloes and ten goats. Ten years ago, his family had around 35 goats, four cows and a few camels, a majority of which were sold in exchange for buffaloes. Buffaloes can be stall-fed and are able to graze by themselves and return home unsupervised. Goats on the other hand need to be supervised for most of the day; they usually pay a local boy to take their goats grazing.

Ram, his sons and daughter are college educated (with bachelor/undergraduate degrees). His two sons and his daughter now live in Jodhpur city where they study and work. Ram himself is

[118] Names of all the farmers have been changed to protect their identities.
[119] Pioneer village refers to a time before the British rule, when certain families came in and marked a certain territory as belonging to their community, in this case *Rajputs*.

a mathematics teacher in a local government school from where he gets his main source of income.

Both Ram and his wife are attached to their land and like to care for their crops. They are careful with the amount of inputs (DAP and Urea) and tillage used. A tractor is rented and used one or two times a year and a disc harrow is only used on alternative years. They mix hybrid seeds with local variety seeds since that is the way to get the best and strongest quality yields that is good for consumption, but are also less susceptible to rainfall variability and wind gusts. In addition to manure from their own livestock, they buy more manure from other herders in the village. Ram says that manure can be expensive but it is very good for keeping the land 'clean' and 'productive'. Ram and his wife are now self-reliant, having over the years struggled with gaining assistance in the *Kumhar* dominated-village. They also have a close-knit community of *Rajput*s living in their vicinity with whom they share their fodder and fuelwood.

After two successive years of below average rainfall, destructive wind gusts, and declining land productivity, Ram Singh has now decided to invest in a tubewell powered by solar energy. The government provides a 70% subsidy for solar panels, under the Rajasthan Solar Energy Policy 2014. He stated that - groundwater availability is decent on his farm (water at 155 feet) but it is of poor quality for growing *rabi* crops like wheat. He instead plans to use the groundwater to grow fruit trees like lemon, pomegranate, mango, ber, among others. At the time of interview, Ram Singh had kept 1 ha of land aside for trialling these fruit trees. He has started gathering information about the fruit trees from other farmers in neighbouring villages who have had some success. In addition, when visiting his children in the city, he occasionally visits research centres (e.g. CAZRI) that provide tree saplings for free.

The AgLiVI ranks Ram Singh as moderately vulnerable (rank of 3); key drivers of his vulnerability include poor quality of land and water resources, and his small landholding size and family (only two members). Through an in-depth qualitative assessment, Ram Singh is instead considered to be in the category of low vulnerability due to:

- Diversified livelihood (crops, livestock, trees, teaching);
- Sustainable land management practices and dependence on traditional land management practices (leaving land fallow, conservation tillage);
- Diversified cropping patterns (mixed and multiple cropping);
- Social cohesion and strong collective capacity with local *Rajput* families; and
- Educated with good access to information sources.

7.3.2 Vulnerable yet resilient

Cluster: I: **Village:** Narayana Nagar **Respondent**: I_NN3 (Dhara Ram)
AgLiVI rank: 2 (low vulnerability)

Dhara Ram's seven-member family belong to the *Jat* community, which is the dominant caste in the village. The family owns a *pukka* house in the village centre with an electricity connection and piped water (supplied twice a month). None of the household members are educated beyond primary school. Dhara Ram owns 12.9 ha of land which he calls, "*sandy, loose soil with low fertility*". In keeping with tradition, he continues to employ diverse cultivation practices during a cropping season. His land is partitioned for varying purposes such as agro-forestry, crops, and pasture, which are then rotated every alternate year. Currently, around half of his land (around 6.5 ha) has been put to long (term) fallow and is not cultivated (due to increased degradation and weed - *P. juliflora* inundation). Of the remaining, he has cultivated (in mixed patterns) *bajra*, *mung*, *moth in* 3.4 ha while 3 ha is left fallow (short-term) for grazing. The family cultivates crops mainly for subsistence. Excess yields are stored for fodder in traditionally built *kothas*, each with a capacity of 2000kg (two tonnes). Water for agriculture is drawn from a range of sources: (i) rainwater is harvested and stored in household tanks and used for around 6 months every year; (ii) since piped water is infrequent, they buy water from tankers (in 2013 he bought 4 to 5 tankers just for livestock), paying as much as 10 USD per tanker containing around 2000 litres of water.

The family own two cows, two sheep, and 17 goats. On average, they sell two goats (rate of Rs.3000/goat), one sheep (Rs. 4000/sheep), and the wool from the sheep per annum. Five years ago, they had 40 sheep and 40 goats but fodder and water scarcity has forced them into owning fewer but higher value livestock (cows). They have five species of agro-forestry on their farm and homestead - *khejri* (60 trees) *rohida* (20), *kumat* (10) - and on their homestead - Ker and Neem (two trees) for shade. All of the products from the trees are used in cooking, fuel, fodder and for homebuilding. For fuel, they rely on a combination of wood and dung cakes from their livestock.

Over the past five years, they have lost almost 50-70% of their *kharif* crop yields due to *Jhola (*wind gusts*)*, depositing new layers of sand on their soil, and low and unseasonal rainfall. Wind gusts, in particular, have increased in the months of August or September, flattening their entire crop (since HYV crops mature at the same time). They have now shifted to sowing a mix of hybrid and local seeds instead of relying solely on HYV seeds. They use a tractor to plough and prepare their land for cultivation approximately three times per season (due to delays in sowing rain) and apply manure from livestock as organic fertilizers on their land.

In order to diversify their income sources, in 2013, Dhara Ram took an informal loan (from a local moneylender) and bought a tractor. When not in use, the tractor is rented out for Rs.300/day during the cropping season. The remainder of the year, two of his sons migrate with the tractor to the neighbouring states of Punjab and Haryana (6 to 8 months of the year). Whenever possible and available, women from the family participate in government-provided MGNREGA employment around the village. In 2013, they participated in around 20 days of work.

The AgLiVI ranks Dhara Ram in the category of low vulnerability (2) due to the diversity of their income sources, large family size, large landholding and diversified cropping patterns. However, upon closer investigation, Dhara ram is likely to be resilient, yet vulnerable. Dhara Ram is vulnerable due to (i) land degradation (half his land is uncultivated due to poor quality); (ii) increasing fodder scarcity for livestock; (iii) water scarcity (he has to buy water from tankers every year); and (iv) dependence on rain-fed *kharif* cropping (variable rainfall and wind patterns). Yet he is resilient due to (i) diverse livelihood options (cropping, livestock, trees, tractor-driving and renting); (ii) crop diversification; (iii) strong social connections and reliable access in the *Jat*-dominant village; and (iv) the use of traditional capacities such as storage of grains for bad years, and the use of rainwater harvesting.

7.3.3 Tipping point of vulnerability

Cluster: II **Village**: Ujaliya **Respondent**: I_Uj3 (Hari Ram)
AgLiVI rank: 3 (moderate)

Hari Ram has a large family of 10 members who belong to the *Meghval* caste (scheduled caste/untouchables) and are at the bottom of the caste and village hierarchy. None of his family are educated beyond primary school. He has around 7 ha of land, 90% of which is under irrigation. Due to low and variable rainfall, groundwater is supplied to both rain-fed *kharif* crops of *bajra*, *mung* and *moth* (all grown separately) and *rabi* crops of carrot, wheat, cotton, chilli and cumin. Hari Ram is of the opinion that the quality of soil has significantly altered. He states that both cumin and chilli have produced zero yields and he is unable to understand why. At the time of the interview, he reported using 250 kg Urea and 250 kg DAP on his land, which is significantly more fertilizer than recommended, even in the more fertile sections of Rajasthan. Groundnut which was a primary crop 10 years ago, doesn't grow on the land anymore. In addition, climate stresses such as frost deposits on the leaves of castor, chilli, rapeseed and mustard have been causing significant losses every year. The family was, in his words, '*about to hit a breaking point*' until investment in cultivating carrot saved them. He has since been getting good returns on the carrot crop; it is less affected by problems such as frost and unseasonal rain.

Hari Ram stated that their groundwater table has fallen significantly over the past four years from 225ft to 825ft, and the water is not as 'sweet' as it used to be, which signifies increasing salinity. He used to irrigate 100% of his land until this year and now he irrigates only 90% of the land, due to the poor quality of groundwater. His view however is that despite this decline in the groundwater table, he is grateful the the groundwater situation is not as bad as in the neighbouring villages of *Rampura Bhatiya* or *Jheepasani* (other Cluster II villages).

Hari Ram owns four cows and four goats. Seven years ago his family had 50 goats and one cow. However increasing loss of pasture land in the village and their limited access to pasture land due to their caste, has meant they had to sell a majority of their goats and buy cows instead (easier to stall feed). A few goats are still kept for meeting their immediate milk requirements when the cows are not milking.

They currently have two types of agro-forestry species, *khejri* (10 trees) and *rohida* (3) on their land. Ten years ago, they had around 100 trees on their farms which were slowly cleared by Haei Ram himself to make way for more irrigated cropland. For fuel, they rely on branches from *P. juliflora* in the village. As they belong to the SC/ST caste, they are entitled to subsidised LPG cylinders and the MGNREGA stipulates SC/ST members be prioritised for employment. However, access to such entitlements has proven difficult for his family. They have also been denied a bank loan recently, due to their caste. Hari Ram stated:

> *"We are constantly judged by the village leaders and Rajput caste members in the village, because we have more land, and a tubewell. They tell us for our caste (of untouchables) we have more than we deserve so we shouldn't ask for more. They want to see us poor".*

He also shared his opinion on why irrigation and increased use of fertilizers is a main coping strategy:

> *"My children will always belong to the Meghval caste, they don't have any education and future hopes except for this land, so we have to get with the times in our village where everybody is making money from carrots. We can't succeed by just sowing bajra, moth, and mung like before".*

Hari Ram, despite having irrigation and moderate quality groundwater, is at the tipping point of vulnerability. He is currently less vulnerable (due to presence of irrigation on 90% of his land). The qualitative assessment puts him at the tipping point of vulnerability. As the groundwater table and quality of water declines, he is likely to face problems in growing traditional crops such as chilli, castor, rapeseed and mustard. Rearing livestock as an additional income source is not feasible in the village anymore, due to degraded pasturelands and his own poor social location. Due to his caste, he is unable to access a majority of government support sources. By shifting to water-intensive crops such as vegetables, and lack of additional sources of income and support, he is likely to become highly vulnerable soon.

7.3.4 High Vulnerability

Cluster: II **Village:** Chaupasani Charnan **Respondent:** II_CC7 (Vijay Ram)
AgLiVI rank: 4 (High)

Vijay Ram belongs to the *Mali* caste (traditional gardeners). He has a large family with 26 members, none of whom are educated beyond primary school. He has 3.8 ha of land which is all cropped in the *kharif* season on which they grow *bajra*, *mung* and *til* (all cropped separately). Five years ago, the entire 3.8 ha was irrigated using groundwater. Subsequently, as groundwater on his farm dwindled, he has had to reduce land under irrigation every year. At the time of this interview, in December 2014, he has no land under irrigation and therefore is unable to crop under *rabi*. He now has two abandoned tubewells and said – "*last year the pressure was so low, that water was just coming one drop at a time*".

He owns two cows and has to buy fodder because there is no pasture land left in the village. During the monsoon, dry fodder is stall-fed to the cows from his own *bajra* crop (stall-fed). During the winter season, he buys bajra/wheat fodder, spending around Rs. 10,000/year to buy (150-160 USD).

On his farmland, there are no trees left as he cleared them all himself 10 years ago to bring more land under cultivation. In his homestead, he has five Neem trees (for shade) and one *khejri*. Cropland is now inundated with *P. juliflora* which according to him has reduced soil fertility. Until 2013, the *P. juliflora* were cleared every year during *rabi*. He used to rent a tractor at around Rs. 600/hour for a day and clear and prepare the land for sowing. Now that he has stopped clearing the land during *rabi*, *P. julifora* is taking over the land. Since he does not own a tractor, he does not want to rent one at such a high expense in November just to clear the shrubs.

His family home has recently started getting some piped water, sourced from the village tubewell. For the remainder of their domestic water requirements they purchase two tankers a month at Rs.300/tanker. Rainwater harvesting was discontinued 15 years ago with the advent of tubewells. For food, they rely mostly on government rations (PDS) but they also have to buy vegetables from the market at a cost of around Rs. 500/month, since the PDS rations are inadequate to meet the food requirements of the 26-member family.

A combination of problems including, land degradation, groundwater depletion, weed inundation, and poor rainfall patterns have forced Vijay Ram to switch back to rain-fed *kharif* cropping, abandoning irrigated *rabi* cropping. Fodder scarcity has led to escalation of fodder costs in all of Jodhpur. Due to the inflated price of fodder, Vijay Ram plans to focus solely on cultivation of fodder crops (*bajra* and *mung* stalks). This, he thinks, will provide fodder for his own livestock and he will also be able to sell it in the market at inflated prices.

Since the family's primary focus over the last 10 years has been on cultivation, they have not participated in any MGNREGA works nor have they been actively involved in other village activities. They have recently started re-integrating with the village community and are ready to participate in whatever work comes in. For instance, several members of his family now work as agricultural labourers on neighbouring farms to make additional income. They typically receive about 25% of the profits from any returns on the land. To supplement income from this, in 2013, they also leased 0.5 ha of their land to their neighbours for Rs. 1000-2000 (30 to 40 USD) for 3 months. The lease was given for the *rabi* season (3-4 months) and the leasee cultivated carrots and radish. Groundwater was sourced from a separate tubewell, where water is available at 900 feet, although brackish and saline. While Vijay Ram is aware that salinity could further degrade the land, he said, "*I am in dire need of some income to feed my large family, so I need to do what I can*".

The AgLiVI value for Vijay Ram is 4, signalling high vulnerability (with a high AgLiVI score of 0.73). The qualitative assessment also places Vijay Ram to be highly vulnerable due to: (i) degraded land with perennial weed invasion and salinity; (ii) lack of groundwater; (iii) loss of *rabi* crop; (iv) absence of pastureland and related change in livestock ownership; and (v) large family but no livelihood diversification or community relationships to rely on.

The above four case histories demonstrate that ranking or typifying vulnerability can provide valuable insights, if the results are supported with rich and nuanced information. This includes exploring the key shocks and stressors that impact on livelihoods, and the key agriculture and livelihoods strategies adopted in response to these changes. The validity of these findings for broader drylands vulnerability research is discussed in the following section.

7.3.5 Targeting vulnerability-reduction

In conceptualising vulnerability as endogenous to a socio-ecological system, a vulnerability index called AgLiVI was developed (in Chapter Six) specifically for this study, building on both existing literature and results of the fieldwork. In triangulating results of the AgLiVI with qualitative analysis, it is found that the index provides results that are relevant and useful in identifying vulnerable villages or households and understanding 'why' these households are vulnerable.

The vulnerability index (AgLiVI), derived for the drylands of Jodhpur, is particularly strong for identifying households that are 'highly vulnerable'. This indicates that current sensitivities and lack of adaptive capacity among vulnerable households are captured well in the index. This is a positive result since vulnerability indices, especially at a local level in India, are most commonly assessed to identify the most vulnerable regions of a given population to target assistance. For instance, under the Paris Agreement, India's Ministry of Environment Forests and Climate Change (MoEFCC) develops vulnerability profiles in reporting to the UNFCCC. The vulnerability profiles are then used for approving areas in need of assistance from a pilot 'Adaptation Fund', and in developing State Action Plans.

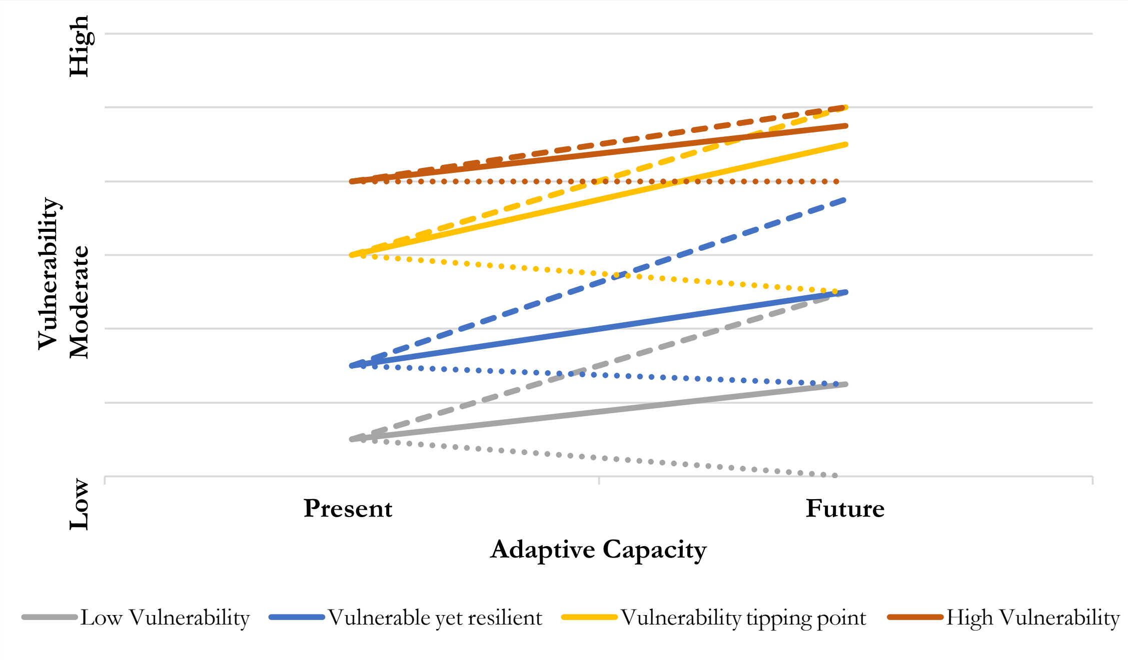
However, one of the limitations of the vulnerability index, that can limit its usefulness for longer-term adaptation and land use planning in drylands, is that the households that fall below a certain 'score' or 'rank' may instantly be deemed to not be in need of immediate adaptation support. Viewing the analysis with a qualitative lens helps resolve this dilemma, adding clarity to the results of the index. The qualitative analysis strengthens the AgLiVI by highlighting the importance of also targeting households in the middle section or at the tipping point of vulnerability. In focussing on the farmer vignettes in section 7.3.1-7.3.4, it is evident that households in this middle section of vulnerability need equal attention from targeted programmes, or they are likely to soon become 'vulnerable' themselves.

This is evident in the example of Vijay Ram, who has been classified as 'highly vulnerable' (see Section 7.3.4). Five years ago, he probably was at a 'vulnerability tipping point' irrigating his entire 3.8 ha of cropland. Over these five years, with the declining quality of both land and groundwater resources, he is now vulnerable. Importantly, if his traditional wisdom and practices were supported; and if adequate support was given to his family recognising their sensitivities five years ago, Vijay Ram would have likely not tipped into being 'vulnerable'. Hari Ram (Section 7.3.3) currently stands at the 'vulnerability tipping point'. If his family continue their current patterns of cultivation and groundwater extraction, five years down the line, it is likely they will have tipped into being 'highly vulnerable'.

Figure 7.3 illustrates potential pathways for those at different stages of the vulnerability spectrum[120]. The different kinds of broken lines show either resilient pathways to the future (dotted lines show vulnerability reducing) or maladaptive pathways to the future (dashed lines show vulnerability increasing). As discussed above, if business as usual continues, those at the tipping point of vulnerability right now, are likely have the highest vulnerability in the future.

[120] These pathways are only conceptual and illustrative and not based on quantitative trends or analysis.

Figure 7.3: Potential adaptive pathways



Source: Author's own

Policies and programmes therefore need to also target households currently in the tipping point of vulnerability, critically scrutinising their current lack of adaptive capacities, reliability of access to resources and institutions and, the sensitivity thresholds of their resources and social systems. It is important for vulnerability research in drylands to recognise the threat of households moving from one vulnerability level to the next, especially from low vulnerability to high vulnerability. While authors have indicated that projecting future impacts and trajectories can bring in large uncertainties into the results of a vulnerability analysis (see Chapter Two and Six), it is critical to acknowledge that even in focussing on the present time, adaptive capacities must be sustainable (i.e. not diminish future generations capacity to use the land).

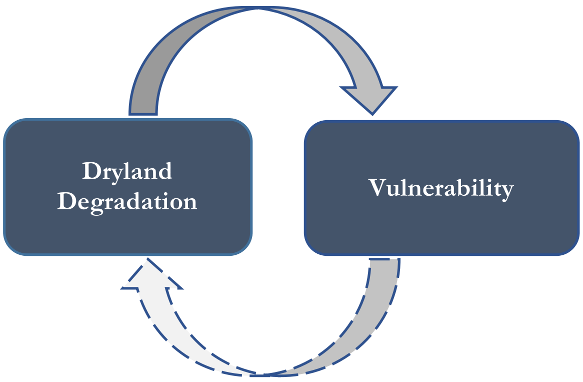
Having established the complicated and dynamic nature of vulnerability in drylands, and the value of using a mixed methods approach (Chapter Four) to explore these nuances, the discussion now turns to clarifying the relationship between vulnerability and dryland degradation. Chapter Two identified the disparate ways in which dryland degradation and vulnerability research are often discussed. Using specific examples from the vulnerability typologies presented in this section, the remainder of this chapter explores linkages with dryland degradation.

7.4 Linking vulnerability and dryland degradation

Vulnerability is often studied as a consequence of land degradation, where communities facing higher risk of land degradation are more likely to be vulnerable. Thus, land degradation and climate change are conceptualised as the 'causes' and vulnerability as the 'consequence' (Chuluun et al., 2014; Salvati et al., 2009). However, as argued in Chapter Two, drivers and consequences of dryland degradation cannot always be separated from each other (Bullock & Houérou, 1996).

Vulnerability here can be defined as not just a 'consequence' of dryland degradation but vulnerability in itself is also a key cause/driver of dryland degradation (See Figure 7.4).

Figure 7.4: Feedback loop of vulnerability and dryland degradation



Source: Author's own

This research provides evidence to support the hypothesis that vulnerability is embedded within dryland agro-ecosystems and can impact on land quality through its influence on resource use and resource access. Vulnerability in the two clusters is a function of the sensitivity and lack of adaptive capacity. The analysis finds evidence that shows that poverty does not equate to vulnerability; vulnerability is higher in Cluster II, where farmers are 'richer' (in all traditional developmental indicators of poverty) in comparison to Cluster I. Using examples of households in different vulnerability typologies, the following sections will summarise key findings on the relationship between vulnerability and dryland degradation.

7.4.1 The connection between dryland degradation and 'vulnerability' can be significant

A review of land management strategies of the most vulnerable households showed that 'highly vulnerable' households often resort to drastic coping strategies that intensify the use of degraded land.

In Cluster I, land management strategies of the 'highly vulnerable' are less flexible due to remoteness, geomorphology and rooted social systems. Two households in this cluster were ranked highly vulnerable (I_DB14 and I_DB15) in the AgLiVI, with scores of 0.71 and 0.72 respectively. Both households reported severely degraded land, that had breached its sensitivity threshold. I_DB14 is a marginal farmer with only 0.5 ha land who has responded to vulnerability by leaving degraded land fallow. His family belong to the *Mirasi* caste of Hindus, who are traditionally musicians and nomads. Camel rearing was their traditional occupation; they travelled through the desert with their camels, playing music while providing transport to other nomads in the region. However, the loss of pastureland has forced them to sell most of their camels. Over time, they settled in Dhadhaniya Bhayla (I_DB), worked as agricultural labourers and bought a small parcel of land. In *kharif*, if it rains on time, they grow pearl millet and pulses for subsistence. They leave the land fallow (short term) for the rest of the year and seek other forms of employment such as driving, construction, or working in nearby camel safaris. The household of I_DB15 on the other hand, has responded to their vulnerability by intensifying production on already severely degraded land. Due to fodder scarcity, the family has sold the sheep and goats and therefore have lost access to organic manure and options provided by alternative livelihoods. I_DB15 is of the view that government subsidised Urea and DAP are now cheaper than buying organic manure in the village. The use of Urea and DAP while beneficial initially, has exacerbated degradation of their land.

In Cluster II, nine households fall under the 'high vulnerability' category with AgLiVI scores ranging from 0.71-0.81. All households in this range have indicated severely degraded land, which is compounded by saline groundwater. A common land management strategy among the 'highly vulnerable' has been to abandon their own degraded land and bone-dry tubewells and lease land from large landholders (typically *ex-zamindars*). In a cluster dominated by ex-*zamindars* who own large sections of village cropland, smaller and marginal farmers are left with no option but to rely on land leasing. In Chapter Six (Section 6.4.4), the implications of short-term leasing contracts on the land itself were discussed. Farmers who lease land for 2-3 years, were found to be less interested in the long-term sustainability of a particular piece of land. They focus instead on deep-tractor ploughing, over-application of synthetic fertilizers and over-extraction of poor quality groundwater for irrigation, so as to gain maximum productivity within the 2-3-year period. In addition, loss of CPRs due to inundation of weeds and misappropriation by local leaders, has led many to shift from semi-pastoralist livelihoods to one solely reliant on cropping. Two of the nine vulnerable farmers also indicated that they have had to shift back to rain-fed farming.

Overall, households who are 'highly vulnerable' often revert to two distinct strategies: (i) drastic coping that often leads to intensification in the use of degraded land, water and biomass resources i.e. maladaptation, further exacerbating degradation; (ii) abandoning cropping entirely or shifting to rain-fed farming (from other livelihoods such as nomadism), in turn putting them in jeopardy of extreme poverty. In tracing land use patterns and coping strategies of these households, it was found that a majority of 'highly vulnerable' households attempt the first strategy. Upon failure of this, they soon move to the second option.

7.4.2 The connection between land degradation and those at 'the tipping point of vulnerability' is strongest

Respondents in the middle-section of vulnerability, especially those who are at their 'vulnerability tipping point' are putting the most pressure on land resources in both clusters. In Cluster I, respondents at the tipping point of vulnerability have indicated that as land becomes increasingly degraded, and organic manure less obtainable, they are abandoning traditional rotational fallow systems, relying instead on intensifying use of their land for maximising the benefits. This in turn is likely to exacerbate existing degradation on their lands, eventually tipping them into highly vulnerable households. Groundwater irrigation in Cluster I has been slow to pick up due to: (i) the extraction and use of groundwater in an area where groundwater is of poor quality is unlikely to yield benefits required to cover initial costs; (ii) farmers are well aware that the use of saline and brackish groundwater will weaken their already degraded land. Despite this, four farmers have now invested in tubewells. If they have a few initial successful years, it is likely that others will soon follow. Eventually, farmers who currently have 'low vulnerability' or are 'vulnerable yet resilient' in Cluster I, may transform into being 'highly vulnerable' themselves, since groundwater is saline and has been projected to soon decline.

In Cluster II, those households in the middle section of vulnerability are intensifying cropping of already degraded land. Many instances are included throughout the thesis of respondents moving from diversified livelihood portfolios to relying entirely on cultivation due to loss of CPRs. Pressures from ex-*zamindars* and land owners to increase yields are growing, and governmental incentives such as free electricity for irrigation, subsidised fertilizers and diesel pump-sets are aiding maladaptive practices. In the vignettes of farming indicated in section 7.3.3 Hari Ram, a scheduled caste (*Meghval*) household in Cluster II, is entirely reliant on crop-based farming for income. In a snap-shot in time, Hari Ram's family are not in need of immediate assistance; they have had a decent crop of carrot in the past year (2013) and their groundwater reserves albeit decreasing are still dependable. However, Hari Ram already reports severe degradation of land. In considering the implications of their current land management strategies (including removal of trees, grasses, double/triple cropping), it is unlikely that the condition of their land will improve. CGWB data (see Chapter Three) shows groundwater reserves in the area to be rapidly declining. In the next five years or likely sooner, his family will inevitably transition to the category of 'highly vulnerable'.

Land use strategies and adaptation planning should also consider farmers who are 'vulnerable yet resilient'. These farmers' management strategies provide ideas of how sustainable land management can incorporate elements of both newer technological innovations while maintaining traditional resilient capacities. For instance, the pastoral component of livelihoods in the region has almost entirely disappeared due to poor management of both cropland fallows and CPRs. However, semi-pastoralism is an integral part of the wider dryland agro-ecosystem and offers significant benefits in maintaining food security in the context of variable climate (as evidenced in section 7.3.1 and 7.3.2). Along with *bajra*, dairy forms the basis of a majority of their food preparations. Importantly, strategies need to ensure that the resilient characteristics within households are supported and encouraged, while their vulnerabilities targeted and addressed.

The analysis conducted in this section provides specific examples of how endogenous vulnerability can have differentiated impacts on land use and land management. Overall, there are several pathways towards sustainable land management available to a land manager. The four typologies presented here are intended to assist practitioners in developing sustainable land management strategies where conservation agriculture is supported and extractive agriculture discouraged. Table 7.1 consolidates the varying parameters of vulnerability discussed thus far into a matrix which incorporates the following aspects, explained in detail in Table 7.2:

- **Biophysical features**: Status of land, water and biomass resources; Sensitivity thresholds of land resources
- **Cultivation practices**: Land management practices; Crop diversification; Irrigation sources; Agroforestry
- **Economic factors**: Livelihood diversification
- **Socio cultural attributes**: Family size; Assets/resources; Social location; Individual and group/collective coping capacity and social support; Education level
- **Technological aspects**: Synergy between traditional and modern adaptation practices
- **Institutional support**: Access to information; Access to benefits from government programmes and services including bank credits.

Table 7.1: Matrix of the key parameters of the four vulnerability typologies

Characteristics of Vulnerability Typologies	Low Vulnerability	Vulnerable yet Resilient	Vulnerability Tipping Point	High Vulnerability
Biophysical features				
Status of land, water and biomass resources (good to severe)	Good	Moderate	Low to Severe	Severe to collapse
Sensitivity threshold (low to high)	Good	Moderate	Low to Severe	Severe to collapse
Cultivation practices				
Land management practices (sustainable/resilient to unsustainable)	Good	Moderate	Severe to collapse	Severe to collapse
Crop diversification (high to low)	Good	Good	Low to Severe	Severe to collapse
Irrigation sources (moderate to severe)	Moderate	Moderate	Low to Severe	Severe to collapse
Agroforestry (good to severe)	Good	Moderate	Low to Severe	Severe to collapse
Economic factors				
Livelihood diversification (good to severe)	Good	Good	Severe to collapse	Severe to collapse
Socio cultural attributes				
Assets/resources (high to low)	Good	Good	Moderate	Low to Severe
Social location (high to low)	Good	Good	Severe to collapse	Low to Severe
Individual and group/collective coping capacity and social support (high to low)	Good	Good	Moderate	Severe to collapse
Education level (good to poor)	Good	Low to Severe	Low to Severe	Low to Severe
Technological aspects				
Synergy between traditional and modern adaptation practices (good to poor)	Good	Moderate	Low to Severe	Severe to collapse
Institutional support				
Access to information (good to poor)	Good	Good	Low to Severe	Severe to collapse
Access to benefits from government programmes and services including bank credits (good to poor)	Good	Good	Low to Severe	Severe to collapse

Good (green) Moderate (blue) Low to Severe (yellow) Severe to collapse (orange)

Table 7.2: Vulnerability typologies and key characteristics used to illustrate matrix in Table 7.1

Vulnerability Typology	Low Vulnerability	Vulnerable yet Resilient	Vulnerability tipping point	Vulnerable
Biophysical	• **Low apparent degradation** of land, water and biomass resources. • Sensitivity thresholds of resources not threatened	• **Moderate to high degradation** of land, water and biomass resources. • Sensitivity thresholds of resources moderately threatened	• **Severe degradation** of land, water and biomass resources • Sensitivity thresholds of resources highly threatened	• **Total degradation** of land, water and biomass resources. • Sensitivity thresholds of resources crossed
Cultivation Practices	• **Sustainable land management practices** including conservation tillage, organic manure application, crop rotation, fallowing • Crop diversification (mixed cropping) • Primarily rain-fed, *kharif* cropping • Irrigation: use of drip irrigation/traditional water harvesting/open wells. • Good quantity and diversity of agroforestry	• **Maintenance of some sustainable land management practices** including organic manure application, crop rotation, fallowing • Crop diversification (multiple cropping) • Primarily rain-fed, *kharif* cropping • No Irrigation • Good quantity and diversity of agroforestry	• **Unsustainable land management practices** such as intensification of agriculture, water-intensive crop selection, application of chemical fertilizers • Limited crop diversification • Double or triple cropping (*kharif*, *rabi* and *zayd*) • Irrigation: poor quality groundwater • Low quantity and diversity of agroforestry	• **Unsustainable land management practices** such as crop intensification, over use of chemical fertilizers, over tillage • Double or triple cropping (*kharif*, *rabi* and *zayd*) • Irrigation: saline groundwater • Absence of agro-forestry • Monocropping or cash crops
Social	• **Strong social location**, likely a dominant Hindu caste and/or pioneer caste • Resource rich with medium or semi-medium land holdings and moderate number of livestock • Strong social cohesion and collective community support • Robust individual and group coping capacities • Tertiary (undergraduate-level) level education • Cultural attachment to the land	• **Strong social location**, likely a dominant Hindu caste and/or pioneer caste • Medium or large-sized family • Marginal, small, medium or large land holdings and moderate number of livestock • Strong social cohesion and collective community support • Strong group coping capacities • Varied individual coping capacities, typically traditional capacities • Primary-secondary level education • Cultural attachment to the land	• **Moderate/poor social location**, • Small to medium land holdings and few livestock • Limited collective social support and community cohesion • Good individual coping capacity, typically reliant on modern coping mechanisms; Dissipated traditional capacities • Good ability to recognize threats • Primary level education • Erosion of cultural attachment to land	• **Poor social location**, likely belonging to SC/ST and non-pioneer caste • Marginal, small or medium land holdings and very few or no livestock • No collective social support and community cohesion • Individual and group coping capacities diminished • Traditional adoptive capacities eroded, including ability to recognize threats • Primary level education • No cultural attachment to land
Economic	• **Diversified livelihood** portfolio extending to non-agriculture related livelihood opportunities	• **Diversified livelihood** portfolio extending to non-agriculture related livelihood opportunities	• **Livelihood not diversified** • Minimal diversification (largely cropping based)	• **Livelihood not diversified** • No alternative livelihood
Technological	• **High synergy** between traditional and modern adaptation practices	• **Substantial synergy** between traditional and modern adaptation practices	• **Limited synergy** with knowledge of traditional practices but slowly eroding • Modern practices are proving unsustainable	• **No synergy** between traditional and modern practices. • Traditional adaptations are eroded and modern practices have proved unsustainable
Institutional	• **Good access** to information and benefits from government programmes and services including bank credits	• **Reasonable access** to information and benefits from government programmes and services including bank credits	• **Limited capacity** to gain reliable access to information and benefits from most government programmes/services including bank credits	• **Poor capacity** to gain reliable access to information and benefits from most government programmes/services including bank credits

7.5 What can decision makers do?

Using key insights developed thus far, this section presents some principles to aid in reforming planning for land management in India in a way that better addresses the dual challenges of vulnerability reduction and resilient land management. Following the principle that poverty is leading to unsustainability, boosting productivity has remained the policy instrument of choice for a wide range of complicated problems in Rajasthan and India. As evident in this thesis, they have sometimes had the opposite effect, incentivising intensification of land use, over-exploitation of groundwater and inefficient use of support services. However, entirely removing policies to boost productivity risks putting those who have just risen above poverty and water scarcity back into it.

It is critical to recognise the role played by real life complexities in creating distortions and barriers, which mean that even when a particular programme is in place to effectively address vulnerability reduction, 'vulnerable' farmers may be unable or unwilling to change current practices. In India's arid drylands, the barriers to effective implementation are many:

- **Legislation and regulation barriers**: Broader national policies put in place by the central government are often difficult to overrule. At times, even when broader policies are well-intentioned, implementation at the local scale is lacking. For instance, legislation on land reforms in Rajasthan sought to apply stricter land leasing agreements to protect tenants (Chapter Five). However, in order to evade these strict rules, land owners in Jodhpur resort to leasing land on informal contracts, which offer less security to the tenant, forcing them to intensify land for maximum returns, leading to land degradation and increased vulnerability;
- **Implementation and management barriers:** Implementation at the local level involves a large number of players including institutions, agents, and local leaders, all of whom are in general keen to maintain their individual seats of power. Implementation in rural India is thus riddled with problems of corruption and bureaucracy;
- **Human and financial barriers**: People may be unwilling or unable to take on certain capacities, due to a lack of knowledge and skills or due to the costs involved. Examples include, high initial costs of solar power for irrigation pumps; and
- **Information and technology barriers**: Knowledge gaps persist in determining how key innovations interact with natural variability in arid environments. This translates directly into poorly designed practices of land and water management.

There is no appropriate technology package in place that includes both traditional and modern technologies to address vulnerability and land degradation. Arid drylands are uniquely placed in the vulnerability and adaptation discourse on several counts. They are temporally embedded systems that are mediated by a complex web of interactions between climatic hazards, exposures, and vulnerability. Just as past histories are relevant, the way drylands are managed today will shape the environment of the future and influence how future stakeholders interact with each other and experience the dryland agro-ecosystem (Folke et al., 2002; Whitfield & Reed, 2012). These considerations combined with the uncertainties associated with future climate change suggest that adaptation strategies in the arid drylands should be based on the following key principles:

(i) **Mainstreaming sustainable dryland management into adaptation planning:** The first step toward planning for sustainable dryland management is to better plan for adaptation. Eliminating vulnerability and building resilience will go a long way in addressing some of the key concerns related to tackling interactions leading to dryland degradation as evidenced throughout this thesis. There are currently few dedicated adaptation planning programmes in India (the pilot NAFCC Adaptation Fund is an exception); there are none in Rajasthan, where adaptation strategies are incorporated within current developmental plans. However, current developmental planning is often directly opposed to sustainable land management strategies, exacerbating the conditions for dryland degradation. For instance, the excessive focus on adapting to rainfall variability through subsiding diesel pump sets for groundwater has led to increased salinity and waterlogging on dryland soils.

(ii) **Recognise that variability of climate, fragility, and livelihood instability are embedded within many dryland communities:** Policies are often too focussed on reducing community exposure to climate variability and drought. However, variability is inherent in arid lands and communities possess considerable knowledge on how best to deal with it. Developmental plans therefore need to make provisions that support traditional knowledge, in addition to recognising their ability to identify newer climatic challenges. Provision of access to agro-meteorological data and weather predictions can also assist communities to better prepare for certain hazards.

(iii) **Focus on gaining reliable information on how key climate variables impact on drylands at different scales:** The analysis has demonstrated the inadequacy of using mean annual rainfall as an indicator in planning for adaptation. For instance, unseasonal rainfall has destroyed crops ready for harvest in the region. These trends are not visible when looking at mean annual rainfall. Similarly, district or national-level aggregated rainfall data hide considerable variations in spatial patterns that occur at a more local level. This was clear when comparing rainfall data across the two clusters selected for study. Different climatic parameters have different implications for dryland degradation.

(iv) **A complete assessment of current drivers of endogenous vulnerabilities is critical for understanding the true benefits of planned adaptation**: This includes understanding local knowledge of socio-economic thresholds, taking into consideration the local power and policies that determine reliability of access and focussing in particular on the sustainability criteria of currently promoted adaptive capacities. Therefore, a shift is needed in adaptation planning that focusses on the embedded functionalities of a system rather than just on outcomes.

(v) **Adaptation that focuses only on the 'highly vulnerable' is not enough for drylands:** It is equally important to recognise and target those who are at the 'tipping point of vulnerability'. The dynamic and temporally embedded nature of drylands means that neither utilitarian nor egalitarian measures are likely to be impactful and something in between is required that targets not just the vulnerable, but also those on a clear trajectory of falling into vulnerability in the near future.

(vi) **Incremental adaptation is likely to be more beneficial for drylands than transformative change**: This refers to plans that are operationalised in incremental steps, where adopting concurrent scientific learning is feasible and building on resilient local knowledge of communities is possible. Using examples from this study, it could include knowledge from those who are currently on the left of the vulnerability spectrum - 'low vulnerability'. For example, farmer I_KB17 who is developing unique agro-forestry-based farming systems for the future, while maintaining traditional capacities such as rainwater harvesting and fallowing. Even 'vulnerable yet resilient' farmers such as I_NN5, who rely on traditional fallowing and mixing local and hybrid seeds provide useful evidence in incremental changes. Transformational adaptations can lead to a complete shift away from current and past knowledge systems and can lead to institutionalisation of maladaptations which are slowly tipping many households into vulnerability.

(vii) **Current strategies focussed on education and alternative livelihoods are inadequate**: The focus on improving skills through education and diversified livelihoods assume that rural farmers are looking for an alternative to rural livelihoods and interested in cash cropping. For instance, development plans assume farmers are looking for alternative homes (for instance in urban areas), alternative occupations (such as working in construction) and income from agriculture. However, all the evidence from the two clusters points to most respondents indicating a keen desire to remain in their village and pursue agriculture. Education programmes are rejected by many, not for cultural reasons (as is commonly assumed), but due to the heavy focus placed on learning skills that add no value to their agrarian livelihoods.

(viii) **Caste, power and gender politics should be key considerations:** These are crucial in determining reliable access to resources. These socio-political factors are generally concealed in traditional vulnerability frameworks under simple taxonomies such as 'gender' or 'income'. They need to be given adequate attention when looking to design vulnerability-reducing policies. Current developmental programmes in both clusters have not been able to circumvent these local power clusters. This is especially important in drylands because these are societies which have been marginalised for centuries, living in remote areas relying on social networks. Unless adequate attention is given to their traditional societies, policies will find it difficult to reach the populations and landscapes they are intended for.

7.6 Conclusions

Overall, past developmental planning has shown that despite a strong push for outcome-oriented, transformative changes, success of land management has been limited in Jodhpur. Evaluated against the key principles highlighted above, it is evident that past reform failures in Jodhpur's drylands are rooted in incomplete considerations of risk. In this chapter, risk as shown to be a result of the relationship between exposures, hazards, and vulnerability. However, developmental assistance in Jodhpur has thus far been focussed heavily on addressing the exposures and hazards, without adequate consideration of vulnerability. In doing so, policies have looked to transform agricultural practices in the region by reducing dryland communities' dependence on their natural climate, characterised by rainfall deficit and drought. This has in turn led to significant shifts in the way society organises itself, and particularly in Cluster II, has led to a loss of traditional knowledge systems and resilience.

Therefore, there is a need for research to develop more practical tools for adaptation, that target vulnerability (and its components of sensitivity and adaptive capacity) as a key element of managing risk. In this chapter, four vulnerability typologies were developed to demonstrate ways through which status and use of land resources intersect with dynamic trajectories of vulnerability. The findings show that the two-way relationship between vulnerability and land degradation is clear and significant in the two clusters studied. The study has demonstrated how vulnerability in itself is a key driver of dryland degradation, contrary to general understandings of the relationship between the two. Importantly, of relevance to global drylands research, the findings emphasise the need to design and target strategies not just for the 'most vulnerable' but also those located in middle section or 'tipping point of vulnerability'.

The analysis in this chapter demonstrates that a first step in addressing adverse implications of exposure and hazards is to develop mechanisms that target vulnerability reduction, while supporting resilience. In focussing on current vulnerability reduction, adaptation planning needs to engage closely with principles of sustainable land management. This is especially critical in drylands whereby resource degradation directly resonates with communities in ways that are becoming increasingly difficult to address in the long run.

The above analysis therefore adds a final layer of assessment to the study's aims and objectives, highlighting the need for strategies that consider the dual challenges of contributing to land degradation neutrality, while planning for adaptation. The final chapter (Chapter Eight) will summarise the findings from this thesis and will highlight broader implications of these findings for global drylands.

8. Conclusions

Globally, land degradation has been identified as a fundamental stumbling block towards achieving goals set for reducing poverty, eliminating inequality, and improving health and well-being. Land degradation is central to many of the 17 SDGs and 169 targets set by the UN to protect the planet and its people. However, land degradation within drylands, where close to two billion people live (UNDP, 2013), continues to remain at the periphery of most international development planning and goal setting. Global efforts to address environment and development often neglect the challenges posed by the variable and dynamic dryland environments. For instance, Huang et al. (2017) show that the Paris Agreement's goal to achieve a 2 degree reduction in temperature will be insufficient for drylands, where warming is expected to be 20-40% higher than in humid lands. This neglect of drylands is even more apparent when looking at a microcosm of the arid drylands in India. This thesis has contributed to this critical research area through an investigation of the varying factors surrounding and exacerbating dryland degradation in Jodhpur, India. It has paid particular attention to the vulnerability of communities and landscapes within the arid drylands of Jodhpur, as a means to better understand socio-ecological system dynamics contributing to dryland degradation.

The lived realities, voices and perceptions of communities in these regions are largely absent in scholarly accounts of dryland degradation. This thesis has demonstrated, through the use of a mixed methods approach, that an awareness of farmers' perceptions and knowledge can help unravel some of the complexities that scientists have been grappling with in understanding dryland degradation.

Through addressing these gaps, the thesis has made several contributions to the existing evidence base and policy discourse, particularly in India. This final chapter synthesises key findings of the thesis and highlights its major conceptual, methodological, and empirical contributions.

- Section 8.1 outlines key contributions of this research towards better understanding dryland degradation and vulnerability;
- Section 8.2 responds to research question one, outlining the research gap, key challenges and contributions of this research to the dual challenges of dryland degradation and climate risks;
- Section 8.3 responds to research question two, outlining how a context-driven framework for drylands can be developed and empirically tested, providing key conceptual and methodological contributions to drylands research; and

- Section 8.4 responds to research question three, providing a framework within which to outline recommendations specific for the study area; and
- Section 8.5 highlights key reflections from the research, focussing on contributions to drylands research in India; and avenues for future research.

8.1 Framing dryland geographies and key contributions

Many authors have suggested the move away from the nebulous, all-encompassing and impractical concept of desertification (Behnke & Mortimore, 2016; Grainger, 2007; Prince et al., 2007; Toulmin & Brock, 2016) They argue for theoretical frameworks that focus on better conceptualising the concept of 'dryland degradation'.

In this thesis, dryland degradation is viewed as a synthesis of complex interactions between climate, ecosystems, and social systems, within inherently dynamic environments. The research has offered new insights into dryland degradation and the various factors surrounding and exacerbating it. In particular, the thesis places these difficult debates in the vastly neglected (by local and global research alike) arid zones of India. It provides empirical data on social and environmental change as well as agriculture and livelihood vulnerability in a marginal, remote, and relatively under-researched area of Jodhpur, India. The mixed methods approach adopted provides deeper explorations of the meaning and processes of 'dryland degradation', 'sensitivity' and 'adaptive capacity' in conditions of profound risk and uncertainty.

In adopting a locally-grounded approach that draws upon multiple local scales, the research demonstrates the value of using a case study approach. Jodhpur represents a unique context; moulded by its cultural legacy, its geomorphology, and its socio-economic and political environment. Thus, the research in some ways provides an exceptional case with certain findings specific to the region. For example, the principal role played by the complicated caste-based politics in determining vulnerability in Jodhpur's drylands.

A common criticism of case study research is the perceived lack of broader applicability (Chapter Four). However, certain findings from Jodhpur's dryland agro-ecologies are relatable to other drylands within India and across the Global South. For instance, drawing on a study of two villages in semi-arid South India, Kattumuri et al. (2017) find that current adaptive strategies are increasing resource degradation. The authors call for practitioners to build on knowledge present in local land management strategies. Giannecchini et al. (2007) in a study in South Africa and Dougill et al. (2010) using evidence from Botswana, demonstrate the role played by weak institutional governance in eroding cultural resilience to climate change.

Adaptation planning that favours reactive reasoning is also a common problem in many drylands (Thomas, 2008b; Brooks et al., 2011; King-Okumu, 2017). In a report for the IIED, Krätli et al. (2015) argue that using equilibrium thinking, drylands variability has been seen as a problem that development can resolve by introducing uniform and stable conditions. The authors include examples from Kenya, where nomadic pastoralists are forcibly settled by introducing policies such as controlled grazing. In Jodhpur, the aftermath of the Green Revolution has in effect forced similar shifts among the nomadic population. In addition, the main aim of policies promoting irrigation in India have been to shield communities from their natural environment - which is a fundamentally misplaced goal in the context of arid lands. As evidenced by the findings, it is instead leading to trajectories that are intensifying both vulnerability and dryland degradation.

Furthermore, the two clusters selected for study are evidently distinct in many ways. This speaks to the applicability of certain aspects of the methodology, such as the agriculture and livelihoods vulnerability framework, to broader drylands. The conceptual framework of analysis (Figure 4.2) has, for instance, been developed keeping in mind key gaps from global drylands literature.

The results therefore provide insights not only into the interlinkages between vulnerability, land use, and land degradation in the two clusters, but also into how these linkages can be explored in regions where institutional complexities and vibrant cultures play an important role in land use management. The following sections highlight how the results and discussion chapters responded to the three research objectives set forth in the introduction of this thesis. Through addressing these gaps, the thesis contributed to the existing evidence base and policy discourse in India.

8.2 Linking dryland degradation, climate hazards, and exposure

Research gap: Only when climate resources are paired with management or development practices can dryland degradation be understood, addressed and appropriate action taken (Sivakumar & Stefanski, 2007). There is however little evidence of the linkages between the two. To overcome this gap and develop a robust and rich evidence base, it is essential to incorporate indigenous and traditional knowledge from those who know these landscapes best (Toulmin, 2009a).

Key challenges: As identified in Chapters Two and Three, significant steps have been taken towards a better estimation of the extent of dryland degradation through advances in remote sensing. Similarly, advances have been made in understanding climate variability and climate change using various modelling approaches. There is however relatively little research on how the two interact in different dryland agro-ecosystems. This is especially relevant to the arid drylands of India; research and policy often cite desertification to be a largely human-led process, yet little research exists beyond estimating the extent of the biophysical processes leading to degradation. Climate models, on the other hand, seek to model and project key rainfall and temperature parameters. Analysis on variables relevant to arid drylands such as wind velocities, unseasonal rainfall, and frost are lacking.

The first research question aimed to examine key components that are influencing status, land use patterns and drivers of degradation in Jodhpur; and its linkages with climate variability. The focus of Chapter Five was on identifying climatic hazards and exposures of socio-ecological systems in Jodhpur.

***Conceptual and methodological contributions*:** This thesis has conducted empirical analysis that goes beyond traditional conceptualisations of dryland degradation and climate change in India by providing a detailed disaggregation of factors surrounding and contributing to dryland degradation. The central aim of analysis conducted in Chapter Five was not to measure or quantify degradation, or use objective frameworks of 'drivers' of degradation. A more flexible and exploratory approach, using mixed methods was applied where the goal is to create a number of dynamic structures emerging from secondary data and then work within those structures to advance theories of dryland degradation using primary data and local knowledge from two selected clusters in Jodhpur district.

***Empirical contributions*:** Results show that land quality in the region has declined, with respondents in both clusters identifying moderate to severe degradation of their land resources. Consensus from both clusters is that a combination of climatic factors and management factors are contributing to degradation. Farmers perceive land quality to be different from land productivity. This finding is particularly important as it is opposed to the UNCCD's current definition of land degradation (Chapter Two) which assumes a decline in biodiversity is met with declines in the economic and biological productivity of land. This contributes to debates by authors such as Rutherford and Powrie (2010); Mortimore (2016) (Chapter Two) who question UNCCDs global definition of land degradation, finding it to be lacking in 'complexity'.

A literature review also showed that, practically, there has been confusion in understanding the differences between natural climate variability (characteristic of drylands) and newer climatic challenges. Some literature argues that climate variability is inherent in drylands and should be studied with caution within studies of risk. However, analysis of climate trends in the study area shows that while rainfall and temperature parameters are inherently variable, this variability is intensifying and newer climatic challenges are now visible.

In analysing trends in climate variability, communities also perceived growing rainfall variability, instability and unreliability of monsoons, increasing temperatures in both summer and winter, and increasing wind gusts. Communities particularly perceived increased unseasonal rainfall in September in combination with wind gusts. This corroborated well with observed rainfall data where mean September rainfall has risen to 116 mm since 2010, compared to a long-term average of 39 mm, leading to significant soil and crop damage. Temperatures in both summer and winter months have risen substantially and continue to be highly variable. Any further temperature rise is likely to cause severe adverse implications putting communities on the brink of disaster risk. This supports evidence by Huang et al., (2017), that limiting the average global temperature increase to 1.5 to 2-degree Celsius (as proposed in the Paris agreement) will be insufficient to protect the world's drylands.

These results demonstrate the need for early warning systems, particularly for newer climatic patterns not yet visible through meteorological data. Respondents shared that incidences of wind gusts have risen significantly. While some limited information exists in the region in the form of data on wind speeds and wind velocities, there are no scientific articles on the phenomena of *Jhola*, where wind blows in many different directions, destroying standing crops and transporting sand across long distances.

The analysis in Chapter Five showed the inadequacy of using aggregated larger-scale rainfall data sets to address impacts of climate variability on dryland degradation at a local level. If the goal is to examine the coupled impacts of dryland degradation and climate change on agriculture and livelihoods, localised station data is likely to offer better results.

The results demonstrate that dryland degradation is an amalgamation of key linkages between climate variability, a variety of land management practices (that are often a response to newer climate risks) and several institutional factors. It shows that the emphasis of research on neat socio-ecological systems, where natural systems and human systems are treated as distinct blocks that interact in a relatively hierarchical manner with simple, clear flows is misleading. It leads to recommendations that are difficult for practitioners to translate within the realities of rural dryland agro-ecosystems.

The next section, shows how vulnerability can be used as a framework to bridge the gaps in exploring socio-ecological system dynamics.

8.3 Developing a context-driven actionable framework of vulnerability

Research gap: The UNCCD's (2013) White Paper I on the impacts of desertification states that an index of the all-encompassing interdisciplinary concept of the vulnerability of communities living in a given dryland environment is still awaited. To this end, Reed and Stringer (2016) state the need to gather evidence on how best to characterise and understand vulnerability and adaptive capacities of agro-ecosystems and human populations in regions affected by dryland degradation, including regions newly susceptible to the consequences of climate change.

***Key Challenges*:** The main challenge faced by researchers and policymakers alike has been the inability to unravel varying levels of interactions between biophysical, social and climatic phenomena that occur across multiple temporal and spatial scales. Dryland researchers have been grappling with difficulties in linking the numerous epistemological choices and methodological approaches available to analyse vulnerability, within the grounded intricacies of dryland socio-ecological systems. In India, there are only a few vulnerability assessments conducted in the arid drylands.

The second research question focussed on better understanding and characterising vulnerability in India's arid drylands. Chapter Six presented a framework and empirically tested its effectiveness for identifying vulnerable sections of the population and drivers of vulnerability in Jodhpur.

***Conceptual and methodological contributions*:** The goal was to make the vulnerability framework applicable practically, through context-specific assessments of relevance to the local communities. For the arid drylands, this thesis argues for a shift of focus from 'outcome' to 'endogenous' vulnerability. In addition, while global vulnerability research grapples with ways to incorporate dynamic trajectories and future vulnerability, this thesis agrees with most dryland researchers that the focus in arid drylands needs to be first in the 'now'. However, in focussing on the 'now', there needs to be acknowledgement of the need for future generations to be able to rely on the land. This thesis argues that there can in effect be a vulnerability framework that accomplishes focusing on current development, but without negatively affecting future generations. While this most likely holds true for all ecosystems, it is particularly relevant for drylands.

In devising methodologies for assessing vulnerability, the analysis uses a two-pronged approach:

1. Development of an agriculture and livelihoods vulnerability index: Chapter Six explored the analytical utility of a vulnerability index (AgLiVI). In doing so, the analysis makes three significant methodological contributions to the development of our understanding of vulnerability indicators for dryland agro-ecosystems through:
    (i) Incorporating a fuller range of indicators:

- Local-level indicators derived from the communities themselves: such as social dynamics including caste hierarchy; maintenance of traditional capacities to adapt (e.g. reliance on rainwater harvesting and storage of food grains) among others;
- Middle-tier indicators typically used by development practitioners and policymakers: such as number of women per household, education and skill levels, among others;
- Whole system indicators used in broader national-level analysis: such as crop diversification, percentage area under irrigation, among others.

(ii) Provision for contrasting agriculture and livelihoods vulnerability analysis across the different scales of households, villages and clusters selected for the study;

(iii) Use of both objective and subjective valuations

2. Enhancing the AgLiVI by incorporating unique qualitative categories for discussion:

(i) Community-based interpretations of the sensitivity thresholds of land resources and society relations;

(ii) Examining reliability of access to resources, institutions, and support services, through the lens of local power and caste politics; and

(iii) Evaluating the potential sustainability of current adaptive capacities.

***Empirical contributions*:** In the context of the ecological, socio-demographic and institutional history of Jodhpur's drylands, both clusters were found to be vulnerable. Drivers of vulnerability were found to be highly localised. The results show differing sensitivity (localised land degradation, groundwater depletion, social cohesion) and lack of adaptive capacity (issues of access, lack of livelihood diversification, loss of traditional coping capacities). Importantly, the way households value assets and resources differ. For instance, respondents in Cluster II view livestock diversity as a limiting factor due to paucity of grazing land and scarcity of fodder; respondents in Cluster I view it as a sign of wealth, due to their importance for food security and dowry.

One of the key findings of the analysis is that context-specific indicators that use both objective and subjective valuations can provide results that are applicable in the context of the two clusters studied. The qualitative analysis adds robustness to the findings of the index, helping explore issues that are difficult to quantify.

The qualitative analysis of vulnerability highlighted the following:

(i) Community-based interpretations of thresholds of sensitivity, showed that land, water, biomass resources, and social systems are threatened and are in an altered, less recognisable state. The study reveals that strong social systems built on cohesion and large joint families, which promote adaptive capacity, are threatened by the emphasis placed on transforming them, modelling policies and programmes around urban-centric models of family and community;

(ii) Scrutinising the 'reliability of access' shows that access is governed by a web of local power structures (including implementing institutions that form the Panchayat Raj) and the complicated language of caste. Households in a good social location were relatively better off in gaining and maintaining access to pasture land and governmental support systems. The role of women in Rajasthan is also found to be relatively misunderstood in vulnerability research, with women's vulnerability rooted in cultural factors; and

(iii) Incorporating discourses of 'sustainability' to ensure current capacities to adapt are not negatively affecting future generations ability to use resources. Many households with strong current individual adaptive capacities are found to rely excessively on unsustainable modes of production, putting even their near-term adaptability at stake.

In this study, analysis from both the AgLiVI and qualitative vulnerability framework shows that Cluster II, despite access to irrigation and technological innovations, is more vulnerable than the more arid and remote Cluster I. Thus, in arid Jodhpur, irrigation and access to markets while providing benefits to both agriculture and livelihoods, are not in themselves enough to moderate and reduce vulnerability. Instead they have, in some instances, led to maladaptation. This evidence emphasises that vulnerability in arid zone agro-ecosystems contrasts with other humid or semi-arid zones of India. Many studies in semi-arid and sub-humid regions of India have shown that irrigation and market access are key vulnerability-reducing factors (Section 6.3). The findings show that resilient attributes of a particular socio-ecological system (i.e. maintenance of traditional capacities, strong social cohesion) play a significant role in mediating vulnerability in comparison with the more productivity-driven technical transformations currently prescribed in arid zone Jodhpur. These findings emphasise that poverty does not necessarily equate with vulnerability and that, in some instances, poorer households were found to be less vulnerable when faced with sudden shocks or stressors.

Therefore, the findings demonstrate vulnerability to be a complex phenomenon; rather than a uniform phenomenon where only the poorest or most marginalised (e.g. women) are impacted. Specifically, the research shows the need to reconceptualise vulnerability with an emphasis on understanding differentiated sensitivities, accessibility, and sustainability of current responses. Current approaches to vulnerability assessment have important benefits, but crucial limitations are evident when placing them in the context of the drylands of Jodhpur. Drylands, in regions like Jodhpur, are naturally variable, dynamic, and culturally embedded. Any uncritical transfer of methodologies, with respect to vulnerability and treatment of risk, needs to therefore be treated with caution, especially when using it as a basis for prescribing solutions to climate risks.

8.4 Vulnerability and dryland degradation: Cause or consequence?

Research gap: A practical understanding of the underlying factors that control dryland degradation and, more broadly, land potential (potential to support multiple ecosystem services and resilience) is necessary to design and target investments in sustainable land management on lands that are at high risk of further degradation (Nkonya et al., 2011; Herrick et al, 2013).

Key Challenges: Many of the solutions offered for the intricate problems of the drylands people and landscapes have not been successful due to top-down research and development planning (Chapter Two). In India, insufficient knowledge exists on how to mitigate the adverse impacts on vulnerable sections of the community while maintaining the inherent resilience of drylands.

Conceptual and methodological contributions: Through analysis conducted in Chapter Seven, it was demonstrated that vulnerability plays a key role in determining how land is used. In a region where land is already significantly degraded (Chapter Five), current uses of land are exacerbating degradation, and bringing newer areas into degradation. Successful strategies to tackle dryland degradation therefore need to take into consideration the vulnerabilities of the system that are leading to adverse outcomes on land. Using vulnerability as an integrating concept helps demonstrate why some communities are successful in governing their land while others are not. Understanding these differences will help better target adaptation polices towards sustainable land use management. Analysis in Chapter Seven shows that vulnerability is not just a consequence of, but is also a key driver of dryland degradation.

Empirical contributions: Evidence from Chapters Three and Five show that Jodhpur has always been exposed to physical hazards but recently climate variability is intensifying. Using a framework of risk (Figure 6.1) this research demonstrated that in areas with high exposure, risks are triggered when a climate hazard, impacts on a vulnerable socio-ecological system. Vulnerability, as evidenced in Chapter Six, is influenced by a wide range of factors, including socioeconomic and political factors (IPCC, 2014). However, neither decision makers nor researchers in India have acknowledged the embedded socio-political vulnerability of dryland communities.

These vulnerability factors combined with current climate variability and exposure together constitute the challenges that drylands adaptation planning needs to address. Among these challenges, some are directly manageable through targeted planning (such as livelihood diversification, institutional support), while others (such as exposure from rainfall, temperature changes) can only be managed by reducing the sensitivity of dryland agro-ecosystems (for instance by promoting drought-resilient crops). Furthermore, there could be several other factors that significantly affect adaptability of drylands under climate change.

The objective of adaptation planning has to be to reduce vulnerability and increase resilience. This can be achieved by reducing sensitivity and increasing adaptive capacity. The arid dryland agro-ecosystems of Jodhpur exist under a unique set of conditions pertaining to: its ecological features; current state of land water and biomass resources; past history of management; local culture and traditions; community social dynamics; local community-based institutions; and the local economy. Therefore, adaptation planning must be tailor-made to a given dryland agro-ecosystem.

Current developmental planning has largely focussed on transforming societies within rural Jodhpur, attempting to reduce their exposure to climatic elements. Analysis showed that the majority of planning and policies have been put in place without adequate consideration being given to the use quality of the land. For instance, the Government continues to focus excessively on irrigation and supplementation of irrigation policies within India. While these might have positive impacts in some regions of the country, in Jodhpur, there is clear evidence that a number of maladaptation practices have become embedded within communities, promoting lock-in by users. Adaptation planning is urgently needed, since the land is already degraded, groundwater levels have declined and water quality has declined.

In 2015, the Government initiated the National Institution for Transforming India (or NITI Aayog) emphasising a bottom-up model for improved participation of civil society, state government and local implementing institutions in planning and implementation. The Government is also committed to making the country land degradation neutral by 2030. However, no major structural changes have emerged since then, and many of the stakeholders at the local level are unaware of these broader policy changes. There remains a need to raise awareness among different levels of government of policy changes occurring at national and state level, and how their participation can be integrated in a way that benefits their communities and resources. Similarly, while monitoring of land degradation has been initiated, there needs to be further capacity building at an institutional level on exploring the causes and consequences of land degradation.

This research proposes a shift in developmental planning, moving from planning focussed on transforming societies to protect them from drought, to one where the focus is on reducing endogenous vulnerability. A necessary first step to strengthen plans for vulnerability reduction is to demonstrate how the vulnerable communities are impacting on land use. From the vulnerability assessment, four vulnerability typologies were developed to target adaptation strategies: (i) Low vulnerability; (ii) Vulnerable yet resilient; (iii) At the tipping point of vulnerability; (iv) Vulnerable. This research demonstrated that, while the connection between dryland degradation and the most vulnerable sections of the community can be significant, it is those at their 'vulnerability tipping point' that are putting the most pressure on land resources in both clusters. Households at a tipping point of vulnerability are also the most at risk of falling into 'vulnerability' in the near future. Therefore, adaptation planning needs to incorporate and target measures that reduce the vulnerability of the most vulnerable and also those at the vulnerability tipping point. Furthermore, planning needs to find solutions for building resilience from within communities, especially looking to sections of the population who fall into the 'low vulnerability' or 'vulnerable yet resilient' category.

A major challenge in this context is to turn local knowledge, traditions, and learning capabilities into suitable institutions for governance that allow adaptive management. Solutions to dryland degradation are not a one-size-fits all and it is essential to tease out what sorts of approaches are likely to work in what contexts (Stafford-Smith, 2016). This will entail significant realignment of ongoing developmental programmes on irrigation, land tenure, and common property resources. In addition, broader national policies, proposed in accordance with the UNCCD regulations, need to be enhanced. Research needs to support more profound reflections on what dryland degradation means to both communities and landscapes, rather than purely stating how much of India's land is degraded.

8.5 Reflections on the research

8.5.1 Drylands of Jodhpur: 'Dreary and barren' or 'vibrant and resilient'?

This thesis finds that the visual simplicity represented in most desertification research in India - of rural dryland farmers in the Thar desert struggling to cope with drought and ever multiplying populations in need of protection and innovation - to be far removed from reality. Instead, respondents were found to be knowledgeable, rich with experiences that have been acquired through observation over generations, accessible and eloquent in their awareness of the long-term implications of certain land management strategies. As one older respondent observed *"As our bodies and souls get older, we need to be more delicate with (them), similarly as our land gets older, it requires more care"*. However, as their land becomes increasingly degraded, less resilient, and their surrounding climate less predictable, dryland farming is entering a new reality. As their ecosystems, food and fuel security and socio-cultural systems become threatened, farmers are more likely to turn toward short-term solutions which may only exacerbate resource degradation in the longer term.

The role of research and policy in addressing this problem is critical. Research must continue to emphasise the significance of and promote the relevance of local scale, bottom-up assessments from different regions of the world. Decision makers in turn must focus on finding innovative ways to improve the resilience of communities, while incorporating adaptation into local land use planning strategies in a synergistic manner. As challenging and utopian as these ideas may seem, achieving targets such as land degradation neutrality and feeding a population of 9 billion by 2050 will require concrete and coordinated evidence-based action that originate at a local level.

As identified in this thesis, a critical first step is for research to understand how diverse social and ecological drivers affect land systems. This is essential to help communities as well as local governments to better understand the value and potential of the land, prevent unsustainable land use and therefore aid in the long-term sustenance of agricultural and livelihood systems.

8.5.2 Future outlooks

Climate change and increasing climate variability in degrading landscapes lead to significant losses for livelihoods. This is palpable, real and happening right now, as evidenced in this thesis. Referring back to the quote by the UNCCD that this thesis started with, understanding and addressing the combined challenges of land degradation and climate is one of the most pressing challenges of the 21st century. There is still much research to be done. Some future avenues of research have become decidedly clear while writing this thesis and are discussed below.

There is a need for the research community to continually adapt to changing climates and circumstances, in the same way that communities are expected to. For instance, while rainfall and temperature parameters are consistently being analysed in climate change research; lesser known parameters relevant to drylands, such as high temperatures, wind, and frost and their interactions with agricultural systems are rarely included in climate research and adaptation planning. Consequently, they receive little attention in designing adaptation strategies. The interactions between different climatic parameters such as temperatures, unseasonal rainfall and wind gusts are also not known. Communities mentioned that the different climatic parameters separately may not cause as much harm as they do together (e.g. the combined impacts of wind gusts and unseasonal rainfall in September is discussed in Chapter Five).

Research is also needed to understand the links between climate risks, dryland degradation, above ground biomass, water, and biodiversity. Soil experiments could not be conducted in the time frame of this study. Therefore, specific information on the implications of biodiversity on soil quality could not be adequately triangulated. For example, linkages with land quality and agro-biodiversity with regard to *P. juliflora* were mentioned by many respondents and further investigation is needed to establish the trade-offs. Faunal biodiversity in particular receives little attention in dryland degradation research. The trade-offs brought on by biodiversity conservation policies with regard to Blackbucks were mentioned briefly in this thesis (Chapter Five). Increasing blackbuck populations have led to problems for farmers, destroying crops and impacting on soil compaction.

Evidence from this study has shown that vulnerability provides a strong framework to explore embedded functionalities of a dryland socio-ecological system. Vulnerability assessment in itself is a challenging task, since it cannot be measured as it lies latent in the system not available for direct observation (Sharma, 2014; Hinkel, 2011). Thus, descriptions and interpretations are largely conducted through proxy indicators and/or characteristics of vulnerability. This presents additional challenges due to limited capability to address complexities and uncertainties present in dryland agro-ecosystems. This study has relied heavily on observations of vulnerability made by the respondents themselves and the assessment has focussed on present vulnerability. More methodological developments are however needed that look into future socio-economic change, risk, and impacts (Räsänen et al., 2016). Importantly in this study, the dynamics of vulnerability are addressed illustrating that people can move into different vulnerability groups as their resources get more degraded and their climate more variable and unpredictable. Further, institutional aspects such as land tenure clearly have implications for both vulnerability, land use and land degradation. There is some evidence on this in research (Ram *et al.*, 1999; Cotula *et al.*, 2004; Toulmin, 2009b) though there remains a need to identify and incorporate these linkages in broader-scale assessments of vulnerability and land degradation.

In summary, this thesis has provided a unique exploration of dryland degradation through the lens of vulnerability in Jodhpur, India with specific focus on incorporating perceptions and experiences of communities. In doing so, this research has made empirical and conceptual contributions to emergent literature on dryland vulnerability and broader studies on the interactions between climate change, land use, and dryland degradation.

The momentum behind researching dryland geographies still needs a significant push; the SDGs (and the push for land degradation neutrality arising from them) offer an opportunity to generate this momentum. In facilitating solutions for land degradation neutrality, context-specific, long-term commitments are required which while focussing on how much of the land is degraded and how many people are using the land, simultaneously aim to understand how and why people are using the land in that way. In this thesis, adaptation planning is highlighted as a first order response to halting dryland degradation and restoring already degraded lands. Importantly, programmes should aim for better co-operation, understanding and inclusion of people in the design of these plans, ensuring research and policy do not underestimate their capabilities to survive within these harsh landscapes.

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Appendices

Appendix I

Land-use categories as defined by the Government of India

Geographical Area: The latest figures of geographical area of the State/Union Territories are as provided by the Office of the Surveyor General of India.

Reporting Area for Land Utilisation Statistics: The Reporting area stands for the area for which data on land use classification is available. In areas where land utilisation figures are based on land records, reporting area is the area according to village papers. In some cases, the village papers may not be maintained in respect of the entire area of the State. In such cases, estimates of classification of area from agriculture census, 2000-01 and 2005-06 are adopted to complete the coverage.

Gross Cropped Area/Total cropped area/Total Sown Area: The total area sown once and/or more than once in a particular year, i.e. the area is counted as many times as there are sowings in a year.

Area Sown more than once: This represents the areas on which crops are cultivated more than once during the agricultural year; obtained by deducting Net Area Sown from Gross Cropped Area.

Irrigated Area: The area is assumed to be irrigated for cultivation through such sources as canals (Govt. & Private), tanks, tubewells, other wells and other sources. It is divided into two categories: (a) Net Irrigated Area: the area irrigated through any source once in a year for a particular crop. (b) Total Net Un-Irrigated Area: deducting the net irrigated area from net sown area.

Total/Gross Irrigated Area: The total area under crops, irrigated once and/or more than once in a year. It is counted as many times as the number of times the area is cropped and irrigated per year.

Total/Gross Un-Irrigated Area: The area arrived at by deducting the gross irrigated area from the gross sown area.

Cropping Intensity: The ratio of Total Cropped Area to Net Area Sown.

Agricultural Land/Total Culturable Land/Total Cultivable Area/Total Arable land: Consists of net area sown, current fallows, fallow lands other than current fallows, culturable waste land and land under miscellaneous tree crops.

Total Un-Cultivable Area/Land: It is the area arrived at by deducting the total cultivable area from the total reported area.

Total Cultivated Area/Land: This consists of net area sown and current fallows.

Total Un-Cultivated Area/Land: It is the area arrived at by deducting the total cultivated area from the total reported area.

Land-use statistics concepts and definitions (Government of India classifications)

Forest Area: Includes all land classified either as forest under any legal enactment, or administered as forest, whether State-owned or private, and whether wooded or maintained as potential forest land. The area of crops raised in the forest and grazing lands or areas open for grazing within the forests remain included under the "forest area".

Area under Non-agricultural Uses: This includes all land occupied by buildings, roads and railways or under water, e.g. rivers and canals, and other land put to uses other than agriculture.

Barren and Un-culturable Land: This includes all land covered by mountains, deserts, etc. Land, which cannot be brought under cultivation except at an exorbitant cost is classified as unculturable.

Permanent Pasture and other Grazing Land: This includes all grazing land whether it is permanent pasture/meadows or not. Village common grazing land is included under this category.

Land under Miscellaneous Tree Crops, etc.: This includes all cultivable land, which is not included in 'Net area sown' but is put to some agricultural use. Land under thatching grasses, bamboo bushes and groves for fuel, etc., not included under 'Orchards' are classified under this category.

Wasteland: This is that land which is presently lying unused or which is not being used to its optimum potential due to some constraints.

- **Culturable Wasteland:** This includes land available for cultivation, whether taken up or not taken up for cultivation once, but not cultivated during the last five years or more in succession including the current year for some reason or the other. Such land may be either fallow or covered with shrubs and jungles, which are not put to any use.

They may be accessible or inaccessible and may lie in isolated blocks or within cultivated holdings.

- **Un-culturable Wasteland:** These are the lands which cannot be developed for vegetative cover. In other words, land which is barren and cannot be put to any productive use, such as agriculture, and forest cover is unculturable wasteland.

Fallow Lands other than Current Fallows: This includes all land, which was taken up for cultivation but is temporarily out of cultivation for a period of not less than one year and not more than five years.

Current Fallows: This represents cropped area, which is kept fallow during the current year.

Net Area Sown: This represents the total area sown with crops and orchards. Area sown more than once in the same year is counted only once.

Appendix II

List of vulnerability indicators

Selected from a literature review of key vulnerability assessments from India

Vulnerability to	Endogenous or exogenous?	Scale of assessment	Examples of Indicators	Source
Climate change	**Exogenous**	**District level**	**Sensitivity:** Dryness (drought sensitivity); Monsoon dependence (average of extreme rainfall) **Adaptive capacity:** Biophysical (depth of the soil, Groundwater availability); Socioeconomic (adult literacy rates, gender equity in a district, % income from alternative economic sources); **Technology** (availability of irrigation; availability of facilities for transport energy, banking, communication, education, and health). **Exposure**: % land under import-competing crops that are less productive	O'Brien et al. (2004b)
Climate change	**Exogenous**	**District level**	**Sensitivity:** Percent net sown area; percent area degraded; cyclone proneness, drought proneness; water holding capacity of soil; percent of groundwater availability; rural population density; area owned by small and marginal farmers. **Adaptive Capacity:** Proportion below the poverty line, percent of SC/ST population, percent workers involved in agriculture; percent literacy; literacy gender gap; no. of agricultural markets; no. of villages with pukka road; no. of villages with electricity, percent net irrigated area, percent livestock population, amount of fertilizer consumption. **Exposure**: Change in annual rainfall; Change in June and July rainfall, Change in maximum temperature; change in minimum temperature; Occurrence of frost days	Rao et al. (2013)
Climate Change	**Exogenous**	**State level**	**Adaptive Capacity**: GDP per capita; Family dependency ratio; Literacy; Population density; Percent land unmanaged; **Sensitivity:** Population at flood risk from sea level rise; Population no access clean water/sanitation; Cereals production/ha; Protein	Brenkert & Malone, (2005)

			consumption/capita; Percent land managed; fertilizer use/ha; Completed fertility; Life expectancy. **Exposure**: Temperature; Precipitation; Extreme weather events; Sea level rise.	
Generic hazards	**Exogenous**	**Local (Himalayas)**	**Adaptive capacity:** Dependency ratio; Education; amount of agricultural land; Electricity; Cooking fuel; Non-agricultural livelihood diversity; Agricultural diversity; Access to loans; Political voice; Access to market; Bus stop **Sensitivity:** Consumption; indebtedness, illness; sanitation drinking water (presence of pipe); Diet diversity; Type of dwelling; Slope, soil quality **Exposure:** Environmental shocks; Socio-economic shocks	Gerlitz et al. (2016)
Generic environmental hazards	**Endogenous**	**Local (Kimsar, Uttarakhand)**	**Sensitivity:** Lack of access to water (Presence of a water source within 500m of HH; percent of HHs without water pipeline); Dependence on environment (Percent of rainfed agriculture); Lack of access to shelter (percent of *kaccha* HHs; percent of HHs without sanitation); Gender (percent of female population); Marginalized communities (percent HHs belonging to SC/ST; Percent below poverty line) **Lack of coping capacity**: Economic capacity (percent HHs without electricity, percent of landless HHs, percent of HHs without gas, percent of HHs without stove, percent of HHs without cattle); Lack of connectivity (percent of HHs more than 500m from a main road); Lack of access to information (percent of HHs without radio and television).	Rajesh et al. (2014)
Generic hazards	**Endogenous**	**Multi-scale (district and local. Karnataka)**	**Sensitivity and adaptive capacity**: Population density; Percentage of SC/ST population; Literacy rate; Percent of marginal landholders; Percent of non-workers; Livestock units/100000 people; Per capita income (3-year average); Cropping intensity; Percentage irrigated area; Total area under fruit crops	Esteves et al. (2016)

Appendix III

Sample household questionnaire guide

Date________________ Village________________Household No.____________ Form No.

Obtain Oral Consent __________________________

Introduction

Can you tell us a bit about yourself and your family?

Can you tell us a bit about your livelihoods?

How long have you lived in this village?

A. Basic demographic data

1. Key information

Form Number:			
Name of the Village			
Date			
Head of Household Name			
Age of information provider:	**Gender:**	**Caste:**	
Name of information provider			
Household (roof) Type: Thatched/RCC/Tile/Sheet	**Electrified**	YES	NO

2. Household: Family details

Family members	Total Number	How many members have attended school/literate?	School till what level	Assets owned (Observed)	Exposure to media and frequency
Adult Male				TV Radio Landline Mobile Phone Refrigerator Bike Cycle Tractor Truck Bullock cart Four-wheeler	News paper Radio TV
Adult Female					
Children <14					

B. Occupation

3. Primary sources of income/livelihood? List the primary and secondary sources of income:

4. Livelihood diversification: In the below table tick all sources of income/livelihood the household relies on and percentage of income from each source, if possible.

Key sources of livelihood	% income from each
Crop Production – own farm **Crop production – leased farm** **Agricultural Labour – on other farms as wage labour** **Livestock (Milk, meat, sheep and goats)** **Agro-forestry (Fruit & fodder trees) on own farm** **Government programmes (list which ones?)** **Others? (specify)**	

C. Agriculture and changes in agriculture

5. Land ownership: How much land do you own? Include all categories of land (not just agricultural land)

Land category	Area (bigha)	Owned (bigha)	Leased (bigha)
Total			
Irrigated Land			
Rain-fed Land			
Agro-forestry Land			
Uncultivated Land			
Others			

6. Changes in land ownership? Has the land ownership pattern changed over the past 10 years? Why? Has it changed a lot from 30 years ago?

7. Land preparation: When does land preparation begin (Which month and after which rain?); Has this changed over the past 10 years?

8. Cropping Pattern (2014) and changes to cropping patterns over the past decade

8.1 Total cropped area (2014): Of the total area you own, how much was cropped?

8.2 What was the total cropped area under *Kharif*?

8.3 What was the total cropped area under *Rabi*?

8.4 What was the total cropped area under *Zayd*?

8.5 Was any land left fallow? Why?

	Under Kharif	**Under Rabi**	Under Zayd
Total area cropped			
Land left fallow			
Any other comments?			

8.6 What are the crops grown under *Kharif*?

8.7 What are the crops grown under *Rabi*?

8.8 What are the crops grown under *Zaid*?

8.9 Has the total cropped area changed from 10 years ago? Why? Elaborate

8.10 Has the total area under Kharif/Rabi/Zaid changed from 10 years ago? Why?

8.11 Have the type of crops grown changed over the past 10 years? How?

8.12 Has the timing of cropping changes in general?

8.13 What are the key reasons for changing the cropping patterns?

9. Record crop details: Area by crop; irrigation; and trend in yield (over 5-10 years ago)

Land use type	Crops	If Irrigated? Y/N How many times?	Area in 2014 (Last Year) - Bhiga	Yield in 2014 (units/bhiga)	Trend in yields over 10 years *(I/D/NC)	Factors contributing to trend in yield (irrigation, rainfall, weeds, pesticides)	% used for home consumption
Kharif							
Rabi							
***Zaid*/others**	.						

10. Crop Related Information (Area, Crop Yield and Fertilizer/Manure/Pesticide Application) during 2014 cropping seasons (Kharif/Rabi/other)

Type	If Mixed crop?		Variety of seed & source (HYV/local?)	Fertilizer application		FIM Manure (desi Khat) Qty applied	Pesticide		Machinery	
	Type of crop it is mixed with?	Type of planting (Row, mixed row etc.)		Type	Qty applied		Application	How many times?	Type of Machine (eg. Tractor, mechanized)	Intensity of use – how many times per cropping season?
Kharif crops										
Rabi crops										
Vegetables										

11. Crop loss - Main crops & causes

<table>
<tr><td colspan="3">Over the last 10 years, how many years was there irrigated crop loss? (no.)</td></tr>
<tr><td colspan="3">Over the last 10 years, how many years was there rain-fed crop loss?</td></tr>
<tr><td colspan="3">Over the last 10 years, how many years was there zayd crop loss?</td></tr>
<tr><td colspan="3">What are the main crops affected? Why?</td></tr>
<tr><td>Crop Type (Kharif or Rabi)</td><td>Most common reason for crop loss – Event (√)</td><td>Crop and % loss in yield</td></tr>
<tr><td rowspan="5"></td><td>Drought</td><td rowspan="5"></td></tr>
<tr><td>Unseasonal rain/Low rainfall/Excess rain</td></tr>
<tr><td>Pest</td></tr>
<tr><td>Frost</td></tr>
<tr><td>Others (wildlife etc)</td></tr>
</table>

12. Irrigation sources and changes in irrigation

12.1 What is the area currently irrigated on your own land or leased land (in ha)?

12.2 What are the sources of irrigation on your cropland?

12.3 Is it perennial or seasonal?

12.4 How reliable is the source of irrigation (high, moderate, low)?

12.5 What was the area irrigated 10/20 years ago on the same parcel of land (in ha)?

12.6 What were the sources of irrigation on your cropland 10/20 years ago?

12.7 Was that source of water perennial or seasonal?

12.8 How reliable was the water from irrigation (high, moderate, low)?

12.9 Irrigation: sources and methods: Tubewells

2014				2005 (10 Years ago)					20-30 years ago				
Sources/ types of irrigation	Area irrigated	No. of tubewells	Depth of tubewells (in ft)	Sources/types of irrigation	No. of tubewells	Depth of tubewells (in ft)	Perennial/seasonal	Area irrigated	Sources/types of irrigation	No. of tubewells	Depth of tubewells (in ft)	Perennial/seasonal	Area irrigated

12.10 Reliability/Quality of water for irrigation

	2014	2004 (10 years ago)	20-30 years ago
Reliability (depth of groundwater table)			
Quality (good, moderate, poor)			
If poor, why? (brackish, saline, heavy?)			

D. Livestock and changes in patterns of ownership

13. Livestock: How many types and number of livestock do you own?

14. Change in livestock pattern: If possible, explain change in livestock composition and number from 10-30 years ago

Livestock	Type (Traditional/ exotic) Mention breeds, if relevant	Number (2015)	Number (2005) – 10 years ago	Number (20-30 years ago)
Cow				
Buffalo				
Bullock				
Sheep				
Goat				
Poultry				
Camel				
Others				

15. Grazing patterns: Are the livestock stall-fed or taken out for grazing?

15.1 If taken out for grazing, explain the key grazing patterns? Have they changed significantly from 10-20 years ago?

	Cropping season (kharif)						Other months					
	2015 (Now)			**2005 (10 yrs ago)**			**2015 (Now)**			**2005 (10 yrs ago)**		
Location of grazing (Forest/ farmlands/ common lands/others?)												
Main Grazing area												
Secondary grazing area												
Persons involved in grazing (√)	**M**	**W**	**C**	**M**	**W**	**C**	**M**	**W**	**C**	**M**	**W**	**C**
Time taken for grazing (in hours/day)												

16. What is the quality and availability of grazing land around your village? Is it adequate for livestock? What are your major concerns with regard to grazing land?

17. Milk production & Sale from Dairy: How much milk do your livestock yield? Is it for home consumptions or sold in the market?

18. Income from sale of goat and sheep: Do you sell livestock every year? If yes, how many do you sell and what is the market rate for goats/sheep?

Livestock	Milk		
	Milk yield (Litres)	**Quantity used for home consumption (Litres)**	**Quantity sold* (Litres)**
Local breed cows			
Buffalos			
Goat			
Camel			

E. Agro-forestry

19. Do you have any agro-forestry species on your farm and homestead? If more than one, fill table below:

Species	Area under trees (only if block)	Number of trees	What are the products? (fruit, leaves) and uses	Yield/tree (No. of fruits, baskets, quintals)

20. What are the different uses for the trees? How many useful species?

21. Have there been any changes in quality and quantity of useful species in the village and your farm?

22. Is the produce for home consumption or marketing? If for income, what percentage is sold?

23. What is the extent of spread of P.juliflora? What is the impact of spread of P.juliflora on crop yields and grass production and explain Implications for impact of P.juliflora on Soil fertility for grass or fodder production?

F. Forest/common land dependence

24. Human efforts: On average, how much fuelwood is collected per year? How often is it collected and by whom?

25. How much of fuelwood and fodder are obtained from cropland/community land/forests?

26. Do you have any major concerns/limitations with regard to availability of fuelwood and fodder? (Y/N). If yes, please elaborate:

Forest products collected	Total annual collection (Kg, loads, baskets) from all sources	Quantity obtained from common forest (%)	Quantity obtained from cropland (%)	Quantity Obtained from Community land in the village (%)	Quantity bought from market	% yield used at home)	% yield sold
Firewood							
Fodder							
NTFP (fruits etc)							
Other							

G. Key livelihood strategies

27. Water Sources and Use for family cooking and drinking

What is the main source of drinking water for your family now?		
What is the secondary source of drinking water for your family now?		
What is the distance to the main source of water?		
Who collects water for drinking/domestic use (men/women/both)?		
What was the main source of water 5-10 years ago?		
What is the reason for change, in main source of drinking water (drought, drying well, drying of open tank etc)		
Is the main source of drinking water seasonal or perennial?		
What is the main source of drinking water for livestock	Cropping season	Other seasons
During summer, how do you cope with water requirement for livestock and domestic use (coping strategies)?		
What are the main concerns with respect to water-use?		

28. Sanitation, Health and nutrition

Do you have a toilet? (Y/N)		If Yes, what is the source of water?	
Do you have a cattle shed? (Y/N)			
Is your household connected with street water drainage?			
Has anyone in the household experienced symptoms of --- During the last year	Malaria; Fluorosis; Asthma; Others?		
% Expenditure on health-related issues during last year, if possible?			
Nutrition	**Good year**	**Drought year/where from?**	
Types of pulses consumed			
Types of vegetables consumed			
Do you grow vegetables on farms/homesteads for consumption and which vegetables			
Meat consumed?			

29. Livelihood support avenues

Livelihood support avenues	Good year	Drought Year
Opportunity for substitution of forest dependence		
Connectivity to market places (Y/N) Pukka road?		
Number of household members migrating		
What type of job after migration? i.e. Skilled/unskilled labour?		
Where are they migrating to?		
Why are they migrating?		
Is it permanent or temporary migration?		
Source and access to loan/micro finance for the family a) Agriculture (Crop loans) b) Livestock c) Others (Family loans)		
Have you taken loans in the last one year?		
What is the source of loan (Moneylender, Bank, co-op)?		

30. Do you feel you have adequate access to government programmes? What are the key opportunities for you from these government pogrammes and what are the key problems relating to them?

31. Government programmes and implications for livelihoods (in the past 3 years)

	Activities participated (e.g. Employment, social)	Scale of implementation (HH, community, village level)	Funds allocated	Implications for good year/drought year
Crop compensation				
Subsidies				
MGNREGA				
Women self-help group				
Desert Development programme				

H. Trends in climate

32. What are the key climate characteristics/variables of your region? (try and gather their perception of typical/normal climate)

33. What are the main climatic factors impacting on the land and your agricultural practices?

34. What are your general perceptions of these key variables over the years?

35. If they mention changes, do you perceive any changes in your climate over the last 10-15 years (compared to past trends – maybe 20-30 years ago)? If yes, what key climatic parameters have changed e.g. rainfall, temperature?

Indicators	Details
Rainfall	
Has rainfall improved/declined? How and what are implications	
Has the duration and timing of the monsoon changed over the years? How and what are implications	
Has the amount of rainfall changed? How and what are implications	
Temperature	
Do you perceive any changes in temperatures (summer or winter)? How and what are implications?	
Wind	
Do you perceive any changes in temperatures (summer or winter)? How and what are implications	

36. Have you had to change your agricultural and livelihood practices in any way? Elaborate and discuss implications these have had on other aspects of your livelihood, example, pastoralism?

37. Other than impacts on cultivation practices, what are your perceptions on how it these climatic factors impact on the quality of your land?

38. Would you like to talk about any other changes in your climate?

I. Trends in land quality – own land

39. Can you say something about the differences in the quality of your land now in comparison with 20-30 years ago? Do you perceive your land to be severely degraded, moderately degraded or unchanged?

40. For all respondents – What does the quality of land mean to you? What are the indicators you use to define the quality of your land? (crop productivity? rainfall? cultural?)

41. For those perceiving moderate or significant degradation – what does degradation mean to you?

42. Factors contributing to status of land? Can you detail all the factors you feel are contributing to degradation of your land? (prompt if needed: (i) climate parameters; (ii) land management practices); Rank or ask - do you perceive one of these factors to be more important that the others?

J. Vulnerability and adaptive responses

43. What are your main reasons for feeling vulnerable? (it is your climate? is it food security? Poverty?)

44. How do these things impact on your daily livelihoods and agricultural practices [not always needed]?

45. Adaptive and coping responses to rainfall variability or other changes

What will you do when there is	First Option/Response	Second Option/Response	Third Option/Response
Unseasonal/delayed rainfall leading to crop loss			
Rainfall deficit/ drought during cropping season			
Crop pest attack & yield loss			
Fodder scarcity due to low rainfall or crop failure			
Livestock disease resulting in loss of livestock			
Frost			
Crop destruction by wild animals			
Unreliable or insufficient electricity for agriculture			
Shortage of water for irrigation			
Other loss or damage			

46. Distress coping practices?

- What are main strategies for distress coping?
- If sale of livestock, how many?
- If land left fallow, how much?
- If migrating for longer-term, how long and where to?

Appendix IV

List of Participants

Household Interviews

Cluster I

Cluster	Sub-blocks (location)	Village	Interview	Respondent details	
				Gender	Age
Cluster I - Shergarh	Balesar	Narayana Nagar	I_NN1	F	30
	Balesar	Narayana Nagar	I_NN2	M	60
	Balesar	Narayana Nagar	I_NN3	M	65
	Balesar	Narayana Nagar	I_NN4	M	35
	Balesar	Narayana Nagar	I_NN5	F	17
	Balesar	Narayana Nagar	I_NN6	M	72
	Balesar	Narayana Nagar	I_NN7	M	52
	Balesar	Narayana Nagar	I_NN8	M	60
	Balesar	Narayana Nagar	I_NN9	M	60
	Balesar	Narayana Nagar	I_NN10	M	58
	Balesar	Narayana Nagar	I_NN11	M	48
	Balesar	Narayana Nagar	I_NN12	M	60
	Balesar	Narayana Nagar	I_NN13	F	35
	Balesar	Narayana Nagar	I_NN14	F	30
	Balesar	Narayana Nagar	I_NN15	M	40
	Balesar	Narayana Nagar	I_NN16	M	48
	Balesar	Narayana Nagar	I_NN17	M	38
	Balesar	Khetasar	I_Kh1	M	50
	Balesar	Khetasar	I_Kh2	F	32
	Balesar	Khetasar	I_Kh3	F	35
	Balesar	Khetasar	I_Kh4	M	22
	Balesar	Khetasar	I_Kh5	M	40
	Balesar	Khetasar	I_Kh6	F	45
	Balesar	Khetasar	I_Kh7	M	NA
	Balesar	Khetasar	I_Kh8	F	60
	Balesar	Khetasar	I_Kh9	M	58
	Balesar	Khetasar	I_Kh10	M	55
	Balesar	Khetasar	I_Kh11	F	35
	Balesar	Khetasar	I_Kh12	M	38
	Balesar	Khetasar	I_Kh13	M	30
	Balesar	Khetasar	I_Kh14	M	48
	Balesar	Khetasar	I_Kh15	F	20
	Balesar	Dhadhaniya Bhayla	I_DB1	F	35
	Balesar	Dhadhaniya Bhayla	I_DB2	F	50
	Balesar	Dhadhaniya Bhayla	I_DB3	F	40
	Balesar	Dhadhaniya Bhayla	I_DB4	F	60
	Balesar	Dhadhaniya Bhayla	I_DB5	F	21

	Balesar	Dhadhaniya Bhayla	I_DB6	M	50
	Balesar	Dhadhaniya Bhayla	I_DB7	M	53
	Balesar	Dhadhaniya Bhayla	I_DB8	M	46
	Balesar	Dhadhaniya Bhayla	I_DB9	M	65
	Balesar	Dhadhaniya Bhayla	I_DB10	M	50
	Balesar	Dhadhaniya Bhayla	I_DB11	F	55
	Balesar	Dhadhaniya Bhayla	I_DB12	M	53
	Balesar	Dhadhaniya Bhayla	I_DB13	M	61
	Balesar	Dhadhaniya Bhayla	I_DB14	M	60
	Balesar	Dhadhaniya Bhayla	I_DB15	M	52
	Balesar	Dhadhaniya Bhayla	I_DB16	M	32
	Balesar	Dhadhaniya Bhayla	I_DB17	M	45
	Balesar	Khari Beri	I_KB1	M	82
	Balesar	Khari Beri	I_KB2	M	60
	Balesar	Khari Beri	I_KB3	F	42
	Balesar	Khari Beri	I_KB4	M	72
	Balesar	Khari Beri	I_KB5	M	82
	Balesar	Khari Beri	I_KB6	M	60
	Balesar	Khari Beri	I_KB7	M	52
	Balesar	Khari Beri	I_KB8	M	50
	Balesar	Khari Beri	I_KB9	F	61
	Balesar	Khari Beri	I_KB10	M	65
	Balesar	Khari Beri	I_KB11	M	68
	Balesar	Khari Beri	I_KB12	M	54
	Balesar	Khari Beri	I_KB13	M	45
	Balesar	Khari Beri	I_KB14	M	62
	Balesar	Khari Beri	I_KB15	M	42
	Balesar	Khari Beri	I_KB16	M	72
	Balesar	Khari Beri	I_KB17	M	77
	Balesar	Khari Beri	I_KB18	F	45
	Balesar	Chauthpura	I_CH1	M	49
	Balesar	Chauthpura	I_CH2	M	65
	Balesar	Chauthpura	I_CH3	M	85
	Balesar	Chauthpura	I_CH4	M	35
	Balesar	Chauthpura	I_CH5	M	50
	Balesar	Chauthpura	I_CH6	M	58
	Balesar	Chauthpura	I_CH7	M	52
	Balesar	Chauthpura	I_CH8	F	70
	Balesar	Chauthpura	I_CH9	M	72
	Balesar	Chauthpura	I_CH10	M	75
	Balesar	Chauthpura	I_CH11	M	30
	Balesar	Chauthpura	I_CH12	M	75
	Balesar	Chauthpura	I_CH13	M	50
	Balesar	Chauthpura	I_CH14	F	70
	Balesar	Chauthpura	I_CH15	M	27
	Balesar	Chauthpura	I_CH16	F	40
	Balesar	Chauthpura	I_CH17	F	61

Cluster II

Cluster	Sub-blocks (location)	Village	Interview	Respondent details	
				Gender	Age
Cluster II - Osian	Osian	Rampura Bhatiya	II_R1	M	24
	Osian	Rampura Bhatiya	II_R2	M	30
	Osian	Rampura Bhatiya	II_R3	F	25
	Osian	Rampura Bhatiya	II_R4	M	37
	Osian	Rampura Bhatiya	II_R5	M	10
	Osian	Rampura Bhatiya	II_R6	M	20
	Osian	Rampura Bhatiya	II_R7	M	31
	Osian	Rampura Bhatiya	II_R8	M	45
	Osian	Rampura Bhatiya	II_R9	M	34
	Osian	Rampura Bhatiya	II_R10	M	28
	Osian	Rampura Bhatiya	II_R11	F	40
	Osian	Rampura Bhatiya	II_R12	M	27
	Osian	Rampura Bhatiya	II_R13	M	65
	Osian	Rampura Bhatiya	II_R14	M	32
	Osian	Rampura Bhatiya	II_R15	M	42
	Osian	Chaupasani Charnan	II_CC1	M	60
	Osian	Chaupasani Charnan	II_CC2	F	25
	Osian	Chaupasani Charnan	II_CC3	M	62
	Osian	Chaupasani Charnan	II_CC4	M	30
	Osian	Chaupasani Charnan	II_CC5	F	NA
	Osian	Chaupasani Charnan	II_CC6	M	71
	Osian	Chaupasani Charnan	II_CC7	M	80
	Osian	Chaupasani Charnan	II_CC8	M	24
	Osian	Chaupasani Charnan	II_CC9	M	84
	Osian	Chaupasani Charnan	II_CC10	M	58
	Osian	Chaupasani Charnan	II_CC11	M	65
	Osian	Chaupasani Charnan	II_CC12	M	45
	Osian	Chaupasani Charnan	II_CC13	M	54
	Osian	Chaupasani Charnan	II_CC14	M	60
	Osian	Chaupasani Charnan	II_CC15	M	46
	Jodhpur	Jheepasani	II_J1	M	40
	Jodhpur	Jheepasani	II_J2	M	52
	Jodhpur	Jheepasani	II_J3	F	60
	Jodhpur	Jheepasani	II_J4	M	81
	Jodhpur	Jheepasani	II_J5	M	50
	Jodhpur	Jheepasani	II_J6	M	68
	Jodhpur	Jheepasani	II_J7	M	68
	Jodhpur	Jheepasani	II_J8	F	NA
	Jodhpur	Jheepasani	II_J9	F	25
	Jodhpur	Jheepasani	II_J10	M	26

	Jodhpur	Jheepasani	II_J11	F	60
	Jodhpur	Jheepasani	II_J12	M	63
	Jodhpur	Jheepasani	II_J13	M	72
	Jodhpur	Jheepasani	II_J14	M	75
	Jodhpur	Jheepasani	II_J15	M	45
	Jodhpur	Jheepasani	II_J16	F	25
	Jodhpur	Jheepasani	II_J17	M	55
	Osian	Bhawad	II_B1	M	65
	Osian	Bhawad	II_B2	M	45
	Osian	Bhawad	II_B3	M	53
	Osian	Bhawad	II_B4	M	52
	Osian	Bhawad	II_B5	M	70
	Osian	Bhawad	II_B6	M	67
	Osian	Bhawad	II_B7	M	60
	Osian	Bhawad	II_B8	M	62
	Osian	Bhawad	II_B9	M	52
	Osian	Bhawad	II_B10	M	45
	Osian	Bhawad	II_B11	M	22
	Osian	Bhawad	II_B12	M	38
	Osian	Bhawad	II_B13	M	40
	Osian	Bhawad	II_B14	M	45
	Osian	Bhawad	II_B15	M	52
	Osian	Bhawad	II_B16	M	50
	Osian	Ujaliya	II_U1	M	45
	Osian	Ujaliya	II_U2	M	50
	Osian	Ujaliya	II_U3	M	50
	Osian	Ujaliya	II_U4	M	53
	Osian	Ujaliya	II_U5	M	70
	Osian	Ujaliya	II_U6	M	44
	Osian	Ujaliya	II_U7	M	NA
	Osian	Ujaliya	II_U8	M	NA
	Osian	Ujaliya	II_U9	M	NA
	Osian	Ujaliya	II_U10	M	62
	Osian	Ujaliya	II_U11	M	52
	Osian	Ujaliya	II_U12	M	45
	Osian	Ujaliya	II_U13	M	40
	Osian	Ujaliya	II_U14	M	70
	Osian	Ujaliya	II_U15	F	50
	Osian	Ujaliya	II_U16	M	43

In Depth-Case histories: List of participants

	Village	Interview
Cluster I	Khari Beri	**I_KB16**
	Narayana Nagar	**I_NN3**
	Dhadhaniya Bhayla	**I_DB5**
	Dhadhaniya Bhayla	**I_DB14**
	Khetasar	**I_K15**
Cluster II	Rampura Bhatiya	**II_RB6**
	Chaupasani Charnan	**II_CC7**
	Jheepasani	**II_J9**
	Ujaliya	**II_U3**
	Bhawad	**II_Bh16**

Appendix V

Sample focus group interview guide

Village………………………………..……….

Date: ……/………/2015

Place…………………

Number of respondents:…………………**Male:** …… **Female**: ……

<u>General Questions</u>

1. What do you think are the biggest concerns (not just climate related) facing your community or village?
2. What do you think can be done to try to resolve these issues? What benefits do institutions and programs in the region provide for these concerns?

<u>Agriculture (key changes to farming practices)</u>

3. How have agricultural practices broadly changed over the years (mixed cropping, tractors, newer crops, soil management etc.)? Motivating factors (climate, economic, policy, other)?
4. The issue of unreliable crop yields has been raised consistently, why are crop yields unreliable? What are the implications for livelihoods?
5. Since crop yields are often tied with climate variability, can you provide specific examples of how much productivity of key crops, vary due to the different climate events brought up in the household interviews (unseasonal rainfall, low rainfall, wind gusts, high temperatures, frost)

<u>Land, water, and biomass</u>

6. What does the land (*zameen*) mean to the community?
7. Why do people grow trees like *khejri*, *rohida* and *kumquat*? Do you think these trees are helpful to soil fertility? How?
8. The issue of land degradation has been raised (in the interviews) as an important issue, what are your views on the state of cropland?
9. What do you think are the key reasons for land degradation? What can you do to improve land quality? What barriers do you face in taking restoration practices forward?
10. What are your views on *P.juliflora*? [brought up often in the interviews]
11. Can you talk a bit about grazing land (scarcity, types of trees and shrubs, quality of land)?
12. [It has been said that there is little grazing land in your village, and it is degraded]. How

long have you faced scarcity of grazing land? What are the implications on your livelihood?

13. What are your views on water scarcity in the region? Relate their answers with the increased availability of groundwater…has groundwater helped address some of the issues you have faced in the past because of water scarcity? What sources of irrigation have increased or improved? Quality of groundwater?
14. Has any perennial source of drinking water become seasonal in the past 5 years? Which sources? What is the state of open wells/*johads*/*baoris* in the village?
15. Why have there been so many changes in shifting breeds of livestock?
16. Issues of fodder grass availability for livestock are mentioned, what could be the reason for change?

<u>Climate variability and change</u>

17. How do describe the climate of your area in the last 10 years? Can you compare it with 20-30 years ago? What are the key variables of importance?
18. Unseasonal rainfall, *jhola*, frost have been described as newer issues in the region, what are your views on these?
19. In what way you do feel these variables interact with various aspects of your livelihood? (crop land, grazing land, quality of resources, food security, agro-biodiversity)

<u>Vulnerability</u>

20. Can you talk a bit about the issue of unreliable or insecure livelihoods in the village? What do you think are some of the underlying causes of insecurity in this area?
21. How do you manage or cope with the insecurity? Can you elaborate on traditional methods used to cope and live within these conditions?
22. How have these traditional methods changed over time?
23. What is the role of newer technologies in supporting agriculture and livelihoods?
24. What is the role of institutions (formal/informal) in supporting agriculture and livelihoods? What are the existing government programmes implemented? What are the reasons for not insuring crops or livestock?
25. Do you have any access to weather related information? If, yes, what type of information do you get (rainfall, drought, pests)?
26. Have you ever considered resettlement to other areas in the country?
27. Is there anything you want to add about climate change, vulnerability, adaptation?
28. What type of information do you require on weather, sowing season, hybrid crops, irrigation technologies?

Appendix VI

Vulnerability index values for Cluster I and Cluster II

Indicators	Cluster I		Cluster II	
	Actual AgLiVI value	% contribution to index	Actual AgLiVI value	% contribution to index
Land degradation	0.073	12.95	0.070	11.22
Sate of GW	0.005	0.95	0.050	8.01
Size of land	0.050	8.97	0.055	8.79
Average crop loss	0.028	4.97	0.028	4.48
No. of crops	0.031	5.48	0.028	4.44
Mixed or mono	0.013	2.22	0.045	7.18
Proportion of area without irrigation	0.036	6.47	0.019	3.01
HYV	0.025	4.52	0.005	0.76
Fertilizers	0.037	6.49	0.033	5.19
Machinery (times used)	0.016	2.88	0.025	4.07
No. of Income sources	0.011	1.87	0.010	1.58
Majority livelihood from agriculture (crop+livestock)	0.017	2.95	0.019	3.08
Livestock owned (type)	0.010	1.78	0.014	2.27
Livestock owned (no.)	0.018	3.28	0.020	3.14
Agro-forestry species (types)	0.015	2.71	0.016	2.56
Agro-forestry species (no.)	0.017	3.07	0.020	3.24
Migration	0.004	0.72	0.003	0.56
No. of HH members	0.007	1.31	0.009	1.47
No. of women	0.008	1.49	0.006	0.98
% of HH members educated	0.019	3.41	0.022	3.57
% of skilled workers	0.027	4.87	0.029	4.57
Caste	0.017	2.98	0.012	1.91
Pukka road	0.005	0.85	0.008	1.33
LPG	0.013	2.37	0.006	0.98
Sanitation	0.005	0.97	0.005	0.81
Moderate access to piped water	0.007	1.21	0.004	0.69
Formal loans	0.011	1.96	0.007	1.16
Informal loans	0.009	1.66	0.010	1.68
MGNREGA	0.012	2.15	0.009	1.47
Rainwater Harvesting	0.004	0.76	0.017	2.71
Storage of Grains	0.010	1.73	0.020	3.19
Total	**0.56**	**100**	**0.62**	**100**

Appendix VII

Glossary of local terms

Angrezi Babul	*Prosopis juliflora*. *Angrezi* translates to English or Foreign *Babul* (or tree)
Bajra	Pearl millet
Dhani	A type of settlement in Rajasthan. It is a small conglomeration of huts. Traditionally, all the families that live in a Dhani are either related to each other in some way or at least belong to the same caste.
Desi Babul	*Acacia nilotica*. Desi translates to local (or Indian) *Babul* (or tree)
Dhaman	*C. ciliaris* – a range grass common in western Rajasthan
Hindi	It is one of the two official languages of India (the other is English) as designated by the government. It is the most common language spoken across India.
Isabgol	Psyllium husk
Jagidar	Are recipients of parcels of land in return for their military services and hold rights to the land and all revenue from it.
Johads	A traditional rainwater storage tank that collects and stores water throughout the year.
Jhola	Sudden and strong winds blowing from different directions. Used here as wind gusts
Khatedar	Tenants of the land who actually till the land rented from the *zamindar*
Kharif	Monsoon crop, including pearl millet, mung bean, moth bean, sesame.
Khejri	*Prosopis cineraria*
Kabja	A type of forced occupation
Kothas	Storage units such as earthernware pots or mud/clay silos for grains.
Kuccha	Houses that are made up of mud, wood, straw and leaves. For instance, huts in rural Rajasthan are referred to as Kuccha homes.
Marwari	Is one of Rajasthan's main languages. It shares 50-65% lexical similarity with *Hindi*.
Panchayat	Literally translates to assembly or meeting of five. It refers to a local assembly, and is the cornerstone of the Indian political administration system
Pukka	Houses that are designed to be more solid and permanent. They are typically houses made of cement and bricks.
Purdah	Literally translates to curtain or screen. In this context, it refers to a veil covering the face of women screening them from men or strangers.
Rabi	The winter crop, irrigated in the region and includes wheat, vegetables etc.
Rohida	*Tecomella undulata*
Sarpanch	The head of a village.
Tehsil	It is an administrative division of India denoting a sub-district.
Tobas	Dug-out pools in the village territory constructed to save rainwater in preparation for drought.
Zaid	Summer crop, including cotton
Zamindar	A larger landowner, especially one who leases his land to tenant farmers.

Appendix VIII

Publications related to this research

Tomei, J and **Ravindranath, D**. (2017). Governing the resource nexus: The significance of land in the Global South. In: Bleischwitz, R. (Ed.). *Handbook on the Resource Nexus*. Earthscan/Routledge (In press)

Kattumuri, R., **Ravindranath, D**. and Esteves, T. (2017). Local adaptation strategies in semi-arid regions: study of two villages in Karnataka, India. *Climate and Development*, 9(1), pp.36-49.

Esteves, T., **Ravindranath, D**., Beddamatta, S., Raju, K.V., Sharma, J., Bala, G. and Murthy, I.K. (2016). Multi-scale vulnerability assessment for adaptation planning. *Current Science*, 110(7), pp.1225-1239.